Machining and Manufacturing of Firearms

SONORAN DESERT INSTITUTE

SCHOOL OF FIREARMS TECHNOLOGY

ISBN: 978-1-945697-25-8

Rev. 6.21

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Chapter 1 - Machine Shop Safety

Introduction

While working in a machine or gunsmithing shop, there are inherent dangers and risks when working with powerful machines and sharp cutting instruments. Maintaining a safe attitude and exercising safe practices will ensure your safety. Every time you work with any heavy machine, or even smaller power tools, make certain you follow these safety guidelines to ensure minimized risk for injury.

SAFETY BASICS

Regardless of the type of shop you plan to operate or work for, there will (or should be) a set of safety rules for the shop and each piece of equipment in the shop. These rules should encompass every aspect of the shop, including the workspace, equipment, and yourself. Before ever setting up a machine, inserting tooling, or holding a workpiece, make certain you understand all of the safety rules for the shop and the equipment you will be using.

Because you will be working with firearms, there are additional safety precautions that must be taken to ensure there are no injuries at the shop. These rules are firearm-specific and do not apply to machine shops that produce parts for other industries. These rules will ensure there are no firearm-related injuries caused by negligence.

- **Treat Every Firearm As If It Were Loaded** – When a customer brings a firearm into the shop for service or repair, you must always assume the firearm is loaded. Unfortunately, every firearm owner does not practice judicious firearm safety, which could lead to a situation where a customer brings a firearm into the shop with a cartridge in the chamber. This means that you **must not point the firearm at anything you are not willing to destroy** when the customer hands the firearm over to you. You must also make certain you **keep your finger away from the trigger** when handling the firearm.
- **Clear Every Firearm Before Performing Any Work** – Before you ever begin to disassemble or work on a firearm, you must make sure you clear it of any live ammunition. There is absolutely no reason that you will ever need live ammunition in the firearm

Figure 1: A clear and safe firearm.

while working on it. Working on any firearm when a round is chambered is a very dangerous situation and must never be done. To clear the firearm, first remove the feed source or remove cartridges from the magazine. Second, open the action and cycle it by hand until the chambered round is extracted and ejected. Cycle the action several times to verify the breech is empty. Visually and physically check the action and chamber and verify there is no ammunition in the firearm. Once you have verified the action is clear and safe, you can begin work on the firearm.

- **No Live Ammunition Around the Workspace** – Not only do you need to remove live ammunition from the firearm, but you must also remove live ammunition from the workspace. If at any point you need to test the function of the firearm, you can use snap caps or dummy rounds. Leaving live ammunition around the workspace can lead to a dangerous situation if someone were to mistake a live cartridge for a snap cap or dummy round. If you must test the firearm with live ammunition, it must be done at the range in a trap or against an appropriate backstop.

PERSONAL SAFETY

When working in a machine shop, you are accountable for your own safety. Machines come with manuals, and employers may provide training or safety equipment, but if you do not exercise safety practices or utilize your training or safety equipment, there is a great possibility of incident or injury. Personal safety begins when you prepare yourself for the workday, long before ever entering the shop.

ATTIRE

The clothing you wear in the shop can have a drastic effect on your personal safety. The machines in the shop are very powerful and produce a lot of torque as the tooling rotates. Loose-fitting clothing, long sleeves, gloves, and jewelry can all become caught in a running machine, and easily and severely injure you in the blink of an eye. If something were to become entangled in the machine, most times the machine would not stop until the safety shutoff was depressed or the item is removed from your body, including body parts.

Appropriate machine shop attire should include clothing that fits and is not excessively baggy. Most shops will require t-shirts (tucked in) over long sleeves, but sleeves can be rolled up as long as they are secure and do not fall easily. Most

Figure 2: Appropriate shop attire.

shops will also require pants over shorts because of the possibility of contact with hot, possibly sharp, splinter-like chips, created when cutting various metals. Most shops will also require closed-toe shoes for the same reasons. Steel-toed work boots are preferred because there is a possibility of dropping heavy metal workpieces.

Appropriate attire also includes things that should not be worn. This includes work gloves and jewelry. Rings, watches, bracelets, and necklaces can all become caught in a running machine and cause injury. Work gloves can also become caught in a running machine and pull your hand into the tolling, causing severe injury. Never wear gloves while operating any machine in the shop.

An apron would also be a preferred (but not required) piece of attire for a machine shop. An apron will protect your clothing from dirt and other debris, as well as provide a place for you to hold other tools or accessories that you may need for the job at hand. The same rule applies to aprons as to other items of clothing: they must fit close to the body and not be too loose or baggy. You must also make certain that the straps on the apron are tied securely and neatly and that there is no chance of them coming undone and becoming caught in a running machine.

Figure 3: A shop apron.

PERSONAL GROOMING

Outside of your attire, your personal grooming can also affect your safety. Long hair or a long beard can become caught in a running machine, the same way loose apparel can. Long hair caught in a very powerful machine can easily be ripped from the body, and in a worst-case scenario scalp the operator. You do not have to shave your head or beard, just secure the hair so that it does not hang away from the body. Hats, hair nets, and hair ties can all be used to keep long hair away from running machines, while beard nets can be used to secure beards.

FOCUS

Personal safety in a machine shop is more than what you are wearing or using: if your focus is not directed toward your work, there is a chance for incident or injury. Lack of sleep, stress, or being under the influence of drugs or alcohol can all take your focus away from the task at hand. Anytime you are in the shop working with machines, all of your focus must be on what you are doing. Breaking your focus while a machine is running can lead to a situation where the part, machine, or tooling becomes damaged, or you become injured because a part of yourself becomes caught in the machine.

When entering the shop, make certain you are rested, are not dwelling on personal issues, are not under the influence of drugs or alcohol, and are ready to work. Do not carry any of your personal problems with you to work; if you cannot

devote your focus to what you are working on, you may want to avoid working until you can. Paying attention to what you are doing is the simplest way to avoid accident or injury.

SAFETY EQUIPMENT

Every time you use a machine or any type of power tool, you must take certain measures to protect yourself from debris, dust, noise, and smoke that are created during the machining process. Metal, wood, and polymer/synthetic chips and dust, as well as coolant and machining fluid, are thrown into the air when high power machines cut into the workpiece. Often, safety equipment will be provided for anyone working in the shop.

The most common pieces of safety equipment are safety glasses and ear muffs. Safety glasses will protect your eyes from flying debris and fluids, while ear muffs will protect your ears from the loud noises generated by the machine's motor and the sound of the material being cut. The Occupational Safety and Health Administration (OSHA®) regulates the use and specification of this equipment and enforces (through fines) the regulations they set forth. OSHA requires that safety equipment be used anytime there is a chance for potential harm or injury. From the OSHA website:

> *"OSHA's eye and face protection standard, 29 CFR 1910.133, requires the use of eye and face protection when workers are exposed to eye or face hazards such as flying objects, molten metal, liquid chemicals, acids or caustic liquids, chemical gases or vapors, or potentially injurious light radiation.*

> *"The Occupational Safety and Health Administration's (OSHA's) Noise standard (29 CFR 1910.95) requires employers to have a hearing conservation program in place if workers are exposed to a time-weighted average (TWA) noise level of 85 decibels (dBA) or higher over an 8-hour work shift.*

> *"Respiratory protection must be worn whenever you are working in a hazardous atmosphere. The appropriate respirator will depend on the contaminant(s) to which you are exposed and the protection factor (PF) required. Required respirators must be NIOSH-approved and medical evaluation and training must be provided before use."*

Figure 4: Eye protection, ear protection, and a respirator.

Not just any safety equipment will suffice. All safety equipment that should be used in the machine shop must be approved by OSHA. Other regulating bodies also ensure that the equipment used will meet the standards set forth by OSHA. The American National Standards Institute (ANSI) and The National Institute for Occupational Safety and Health (NIOSH®) both regulate and regularly test equipment intended for use by the public. All safety equipment that meets these standards will be marked to verify it meets the standards set forth by these certifying bodies.

Machine Safety

Once personal safety has been addressed, you can focus on the safety protocols associated with the machines. Each machine operates in its own manner and creates unique safety challenges that must be addressed. These unique safety challenges can all lead to different causes for incident or injury, so a complete understanding of how each individual piece of equipment is used is critical.

TRAINING

Before ever touching a machine or piece of equipment, you must be trained on the proper use of the machine. Most machinists have completed training through a trade school or through on-the-job training through a machine shop. Most machine shops will not hire you if you do not have some type of machinist training.

If you have never used a specific machine or piece of equipment, do not assume you understand how to properly operate it. In the average gunsmithing shop, you will encounter many different machines, including the mill, lathe, drill press, grinder, and buffing wheel. If the shop performs wood work, you may also be working with various powered saws and sanders. Different types of machines and the nuances between manufacturers may lead to a situation where you are unfamiliar with the operation of a machine. The introduction of electronics and automation may also lead to a situation where you are unfamiliar with the function of a certain aspect of a machine.

Anytime you encounter a new piece of equipment, you should also read the operator's manual. Between training and the manual, you should have an understanding of how the machine functions, how to operate it, and how to maintain and repair it. Never operate a machine or piece of equipment without fully understanding how it operates.

GUARDS AND SAFETIES

Modern machines are often equipped with guards or safeties designed to prevent injury or to halt the machine when injury occurs. Guards are designed to prevent hands from coming in contact with the moving parts of the machine. Various saws, grinders, buffers, and sanders will typically feature a metal or plastic guard that covers the blade or abrasive, but still allow room for the work piece to pass through.

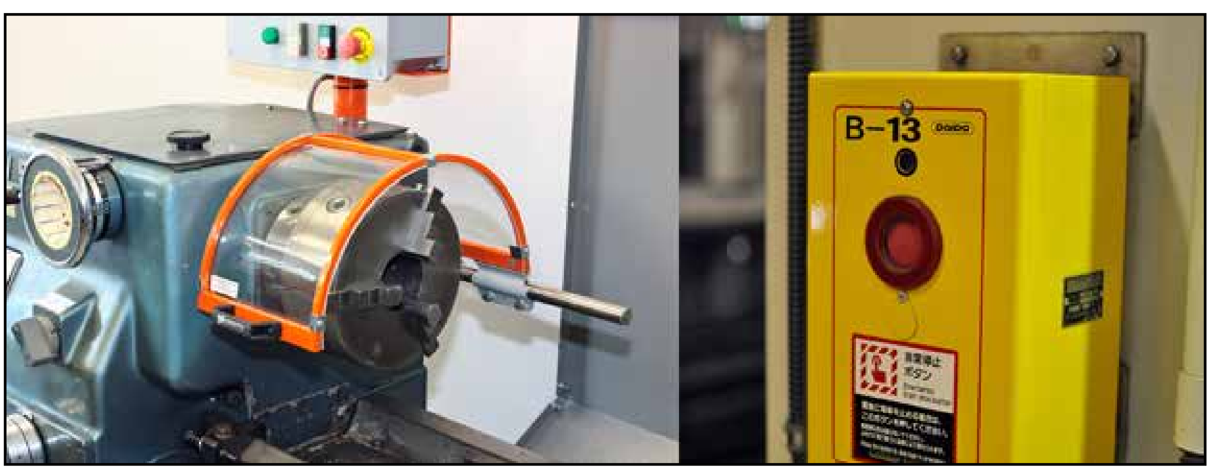

Figure 5: A hand guard and an emergency stop.

Figure 6: Holding a small part against a grinding wheel.

Safeties vary, but the most common devices are emergency stops and brakes. An emergency stop is typically an oversized button that immediately shuts the machine down. An emergency stop can typically be found on most machines, and does not prevent incident or injury but rather limits it. An emergency brake is typically a lever found on lathes and performs the same basic way as a stop.

Never try to remove or modify guards or bypass safeties. Altering the safety of a machine may lead to injury or incident and will void the manufacturer's warranty (if applicable). Refer to the operator's manual if you are unsure of how a guard or safety is supposed to operate.

HOLDING AND ADJUSTMENTS

Once you are ready to begin working on a project, you will need to consider how to hold the workpiece and the tooling, especially with both mills and lathes. It is very important to secure the workpiece and the vise or clamps that are holding it. If the workpiece or holding device is not secure, there is a very high chance that the workpiece, vise/clamps, or tooling will become damaged, break, and possibly cause injury from flying shrapnel. Never begin working before verifying that the workpiece, vise/clamps, and tooling are all secure. Also, verify that the vise/clamps will not interfere with the path of the tooling.

Never try to make adjustments to the workpiece or the vise/clamps with the machine running. There is a high probability of injury or incident from getting tangled in a running machine. Always make sure to turn the machine off before making any adjustment to the tooling, vise/clamps, or workpiece, and always make certain to remove any tools (wrenches or sockets) used to make adjustments to the machine or the vise/clamps.

MOVING MATERIAL

With some machines, such as saws and sanders, the workpiece is pushed into the blade or abrasive instead of the tooling moving into the workpiece. The workpiece is often pushed into the blade or abrasive by hand. For smaller pieces, a push block or push stick is used to move material into the blade. A push block/stick will prevent hands or fingers from coming in contact with the blade, while still allowing the workpiece to be cut. You may also use a pair of pliers (locking or not) or smooth jaw vise grips to hold smaller pieces against a grinder or sander. Metal parts will heat up very quickly and could cause burns to hands or fingers. Never try to move small workpieces or thin material into the blade or abrasive by hand. Anytime hands or fingers come near the blade or abrasive there is always a high chance for incident or injury.

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Shop Safety

The final aspect of safety in a machine shop is the safety of the shop itself. Although you may understand how to keep yourself safe and how to safely operate the machines, the environment itself may be dangerous to work in. Make sure that the shop is set up for the type of work you plan on performing.

SHOP LAYOUT

The layout of the shop can be as crucial to your safety as any other aspect of the shop. An ideal layout would allow you to access each machine from every side. This would allow you to take full advantage of the functions of the machine as well being able to service and clean around it. You will also want enough space between machines to move freely and to work with bigger or longer workpieces. You do not want the machines too close together or the workspace to be cramped, as you may bump into something while working and cause an accident.

Setting up the "flow" of the shop can also add to the safety of the shop. This means that the machines are arranged so that the workpiece can move from machine to machine in sequence of operations, like moving from a saw to a sander and then to the buffer. This will allow you to work more efficiently and will allow you to focus more on the work than on your surroundings.

Part of the shop layout should also include storing all of the tooling, tools, and accessories needed to run and maintain a specific machine near the machine. Storing and organizing all of your tools and accessories neatly near the machine will allow you to easily access everything you need to complete a specific task without having to look for things and breaking focus. Having everything needed to maintain a machine near the machine will also increase the likelihood of maintaining the machine.

LIGHTING

Adequate lighting in the workshop will ensure that the machine, tooling, and workpiece are highly visible so that there are no incidents because of not being able to see what you are doing. If the shop or workspace is dimly lit, you may not be able to see if there is an issue with the machine or tooling, or if your hand or fingers are nearing the cutter. Ideally, the shop would have many overhead lights and each machine would have its own work light focused on the work area. A clamp-on adjustable work light may also be a viable option for lighting the workpiece and work area. If you cannot clamp a work light onto the machine, you may be able to use a headlamp for more light.

CLEANLINESS

The cleanliness of the workshop and the workspace will have a great effect on your shop safety. A clean, well-organized shop is always going to be safer than a dirty, cluttered shop. During the discussion about shop layout, tool storage was discussed briefly. Leaving tools all over the workspace and machine can lead to accidents or incidents. Tools left on a running machine can "walk" into the path of the tooling or blade due to the slight vibrations from the machine's motor and linkage. Tools left cluttered on the workspace may not allow you to set the workpiece down or may cause you to damage the workpiece by setting the piece down onto a tool.

Make sure to pick up tools off of the floor and do not leave things in the path of walkways. Power cords from machines and work lights should be tucked away so they do not create a tripping hazard. If a cord is left in a walkway, make sure to tape it down or secure it so it does not create a tripping hazard.

Make sure to also clean up messes created during various machining processes. Coolant, oil, metal chips and dust from both wood and plastic are thrown into the atmosphere during the

Figure 7: Never use compressed air or a compressor to clean a machine of dust or metal chips.

machining process. Oil and coolant left on the machine or workspace can become an eye hazard or a possible skin irritant if splashes occur. Oil spills left on the floor can cause a slipping hazard. Dust and metal chips can cause eye, skin, and respiratory hazards if they are allowed to accumulate and are blown into the air. Clean all messes after you have completed working and have turned off the machine.

DUST AND CHIP COLLECTION

Dust and chip collection can be beneficial to the safety of any shop by removing harmful dust and debris from the environment. Dust collection systems are available with a centralized collector (vacuum) and a hose or hoses that attach to a machine and collect dust and metal chips as the machine creates them. For smaller shops, a wet/dry shop vacuum may be a better solution for dust collection. The small vacuum can be rolled around to each machine, while the long flexible hose can be positioned to collect the most dust.

Never use compressed air or a compressor to clean a machine of dust or metal chips. The air will blow dust and chips into the air, which could become eye and respiratory hazards. The air will also blow dust and chips into the machine, which could get into the motor and other hard-to-reach areas, potentially causing damage to the machine. Brush away as much debris as possible and use a shop vacuum to collect the rest. The vacuum will pull dust and debris away from the machine's motor and hard-to-reach areas.

Chapter 2 - Fundamentals of Metallurgy

Figure 1: Different materials found on firearms.

Introduction

Firearms and their accessories are made from many different materials. Even parts that share functional commonality (like a rifle and pistol barrel) may be composed of similar, but different, materials. You may wonder why there are so many types used or why some are better than others. A majority of the reasons so many types are used can be tied to cost, purpose, and performance. When shopping for firearms and accessories it would be helpful to understand what you are actually paying for. If you are a hobbyist or professional gunsmith, it is important to understand why a certain material is preferred as an upgrade over another or how to machine or form other materials.

The following is a guide to the most used/popular materials found on firearms and accessories and why they are used. This guide also covers many of the most popular material-forming processes used to manufacture certain parts. Material treatments designed to enhance the life and performance of certain materials is also discussed.

Materials

STEEL AND STAINLESS STEEL

Steel is an alloy of iron and other materials, such as carbon (up to 2.1% by weight). The addition of carbon to iron will change its ductility to hardness. It is widely used in the construction of firearms, especially in frames, barrels and bolts/breech faces/slides. Steel is a preferred material because of its high tensile strength and relatively low cost. Steel is also very popular because of its ability to be formulated (alloyed) to meet specific needs, such as hardness and ductility or corrosion resistance. The material properties of steel can be enhanced with the addition of manganese, chromium, nickel, iron, tungsten, molybdenum, boron, titanium, vanadium, cobalt, niobium, phosphorus, sulfur, silicon, and trace amounts of oxygen, nitrogen, and copper.

Stainless steel is a very popular alloy of steel, containing at least 10.5% chromium by weight. Iron carbon steel will form iron oxide (rust when exposed to water or moisture in the air), but the addition of chromium in stainless steel will form a barrier of chromium oxide that creates a protective barrier that prevents oxygen contact on the steel's surface. Stainless steel is regarded for its corrosion and abrasion resistance as well as its strength at elevated temperatures and strength and ductility at cryogenic (-300°) temperatures.

17-4 PH Stainless Steel – 17-4 PH is a form of age-hardened stainless steel. 17-4 has a lower percentage by weight of carbon (.07%) and a higher percentage by weight of chromium (15% – 17.5%) than other stainless steels. Depending on its heat treat, it can be hardened to 35 – 45 Rockwell C. Because of the higher chromium ratio, 17-4 tends to be more corrosion-resistant than other hardenable stainless steels. Because of its overall stiffness, 17-4 is more of a specialty stainless steel used on benchrest rifle barrels. And because of its low temperature, air-cooled heat treat (between 900° F and 1,400° F), prolonged exposure to high temperature (rapid semi-automatic or automatic fire) will ruin its temper and cause excessive wear on the barrel. 17-4 is also in limited use because of high cost and difficulty in forming but is a popular material used in firearm suppressors. Ultimate tensile strength: 150,000 – 210,000 psi. Yield strength: 145,000 – 195,000 psi.

416R Stainless Steel – 416R is a form of stainless steel that was specifically designed for use in precision, match-grade barrels. It features a higher carbon content (.12%) and lower chromium content (12.5%) than 17-4 PH stainless. 416R can be hardened between 24 and 36 Rockwell C, depending on heat treat. Because 416 was designed for gun barrels, it has very high strength, stiffness, formability, and corrosion resistance. 416 also produces smooth, uniform surface finishes that make bores easy to lap and polish. 416 provides many favorable characteristics, but one downside is in cold

Figure 2: 416R stainless steel barrel.

weather (0° F and below): 416 barrels may fail when used at temperatures below 0° F. 416's cost is lower than 17-4, but still much higher than carbon steel. Ultimate tensile strength: 75,000+ psi. Yield strength: 40,000+ psi.

4130/4140 Chromoly Steel – 4130 and 4140 are similar grades of carbon steel used widely in commercial, semi-automatic rifle barrels. The main difference between 4130 and 4140 is the amount of carbon (.30% for 4130 and .40% for 4140) and manganese (.4% – .6% for 4130 and .75% – 1.0% for 4140), but both contain the same amounts of chromium (.80% – 1.10%) and molybdenum (.15% – .25%). The additional carbon makes 4140 slightly harder and stronger than 4130. Neither 4130 nor 4140 are corrosion-resistant and are extremely susceptible to abrasion. 4130 has a normalized Rockwell B hardness of 93, while 4140 has a C hardness of 32. Because of the lack of corrosion resistance, most 4130 and 4140 barrels are hard chrome lined to prolong the barrel's service life. 4130 and 4140 also do not perform as well under high heat. The low to medium cost of 4130 and 4140 also make it a very popular material for large production firearms. Ultimate tensile strength: 97,000 psi (4130); 148,000 psi (4140). Yield strength: 63,000 psi (4130); 95,000 psi (4140).

4150 Chrome Moly Vanadium Steel – 4150 is a carbon steel similar to 4130/4140 but with the addition of vanadium (.2% – .3%). 4150 also has a higher carbon content at .41% – .49%. The addition of vanadium increases 4150's life at high temperature (rapid and automatic fire) over 4130/4140. The additional carbon also makes it harder and stiffer. 4150 still requires chrome lining of the bore because it is not corrosion-resistant. Depending on heat treat, 4150 can achieve a Rockwell B hardness of 92. The cost of 4150 is also higher than 4130/4140 but still lower than most stainless steels. Ultimate tensile strength: 106,000 psi. Yield strength: 55,100 psi.

8620 Steel – 8620 is a form of carbon steel alloy with a carbon content from .18% to .23%. 8620 is a type of chromoly steel (.4% – .6% chromium; .15% – .25% molybdenum) that can be case hardened, giving it exceptional wear characteristics. 8620 is typically used in bolts and other parts that may experience high wear and cost effectiveness. 8620 can be hardened from 80 Rockwell B to 90 Rockwell C. Ultimate tensile strength: 76,900+. Yield strength: 55,800+.

9310 Steel – 9310 is another form of carbon steel alloy similar but superior to 8620 and C158. 9310 has a very high chromium (1% – 1.4%) and nickel content (3% – 3.5%), making it extremely strong and hard. 9310 is a popular material for bolts and other parts where high strength is required. 9310 can be hardened to between 20 and 40 Rockwell C. The cost of 9310 is often higher than 8620 and C158. Ultimate tensile strength: 179,000 psi. Yield strength: 143,000 psi.

Carbon Steel – Carbon steel is a generic term for any iron carbon-only alloy. Steel is considered "carbon" steel when it doesn't require the use of chromium, cobalt, molybdenum, nickel, niobium, titanium, tungsten, vanadium or zirconium, or any other element to be added to obtain a desired alloying effect. Carbon steel will feature small amounts of copper (not exceeding 0.40%), manganese (1.65%) and silicon (0.60%). Carbon steel is also a generic term for steels other than stainless.

Carpenter 158 Steel – Carpenter 158 or C158 steel is a type of case-hardened, carbon steel alloy. Carpenter steel is a product of the Carpenter Technology Corporation and there is not very much info about its composition. It does have fairly low carbon content (.10%) but a high percentage of nickel (3.5%) and chromium (1.5%). Because of the ability of C158 to be

Figure 3: Aluminum parts.

case hardened differently from its core hardness, case hardness is typically around 61 Rockwell C, while its core is around 38 Rockwell C. C158 is most commonly found in bolts produced by high volume manufacturers and is typically cheaper than 9310. Ultimate tensile strength: 170,000 psi. Yield strength: 140,000 psi.

Spring Steel – Spring steel is a generic name for a variety of steel designed for making springs. Spring steel ranges from low alloy medium steel or high carbon steel to alloy or stainless. Spring steel has very high yield strength. The high yield of spring steel allows it to handle large deflection and twisting forces without plastic (permanent) deformation. Composition ranges by type, but it is typically carbon, manganese, phosphorus, sulfur, silicon, chromium and nickel. Rockwell C hardness ranges from 31 to 60.

Aluminum – Aluminum is a chemical element and is the third most abundant element on earth. Aluminum is a soft, extremely ductile, durable, nonmagnetic and lightweight metal. It is also remarkable in the fact that it is very corrosion-resistant. It gets its resistance from a thin surface layer of aluminum oxide. Aluminum is also a very good thermal conductor. All of these properties make aluminum a fantastic choice for noncritical parts that require light weight and high strength. Aluminum is used in frames and receivers, rimfire bolts and slides, stocks, handguards, and grips, as well as many other parts; it is also used in the cases of pistol cartridges. Aluminum is popular because of its cost and its ability to be alloyed.

6061-T6 Aluminum – An alloy of aluminum containing chromium, copper, iron, magnesium, manganese, silicon, titanium and zinc. T6 refers to the type of heat treat the aluminum receives, which is a two-part heat/quench and age hardening process. Rockwell B hardness is 60. 6061 is used extensively in many different firearms, from pistols to rifles and shotguns. It is an extremely capable material for use in firearms and is relatively inexpensive, but is inferior to 7075 and 7175 in many applications. Ultimate tensile strength: 45,000 psi. Yield strength: 40,000 psi.

7075-T6 Aluminum – An alloy that uses zinc as its primary alloying compound (5.6% – 6.1%). It also contains more magnesium (2.1% – 2.5%) and copper (1.2% – 1.6%) than 6061.

7075 undergoes the same two-part hardening process. Rockwell B hardness is 87. In most cases, 7075 is a high performance substitution for 6061 and so demands a slightly higher price. Ultimate tensile strength: 83,000 psi. Yield strength: 73,000 psi.

7175-T73 Aluminum – 7175 is a similar alloy to 7075, but in a much purer form. 7075 uses less silicon, iron, manganese, and titanium than 7075. T73 also refers to a heat treat that is similar to T6 under more controlled conditions, making it more resistant to corrosion and stress. 7175 is hardened to Rockwell B 82. It is quickly becoming the high performance replacement for 7075 and is the highest priced of the aluminum alloys used in firearms. Ultimate tensile strength: 73,200 psi. Yield strength: 63,100 psi.

OTHER METALS

There are many other metals used in the construction of firearms and accessories as well as cartridges. Shims, spacers, and bushings, as well as coatings and performance parts, are all made from various other materials. Even many of the components of the cartridge are made from nonferrous metals like the case, primer, jacket, and core of the bullet.

Alloy – Alloy is a term used to describe a base metal that is mixed with other metals or elements. Alloys were developed to improve the material characteristics of base metals and were designed to suit specific needs. Many of the metals found in firearms are alloys specifically designed for a single purpose. Even common materials we encounter every day are alloys. Brass and bronze are alloys of copper, and stainless is an alloy of steel, which is an alloy of iron. Alloys are also used to reduce cost or increase formability.

Brass – Brass is an alloy of copper. The primary alloying element is zinc. Brass has a fairly high rate of malleability, which makes it perfect for cartridge cases. It is susceptible to work hardening from being fired and reloaded multiple times. The constant expansion and contraction will eventually cause stress fractures in the brass case. Annealing will soften the brass back to a useable state. Brass can have a Rockwell

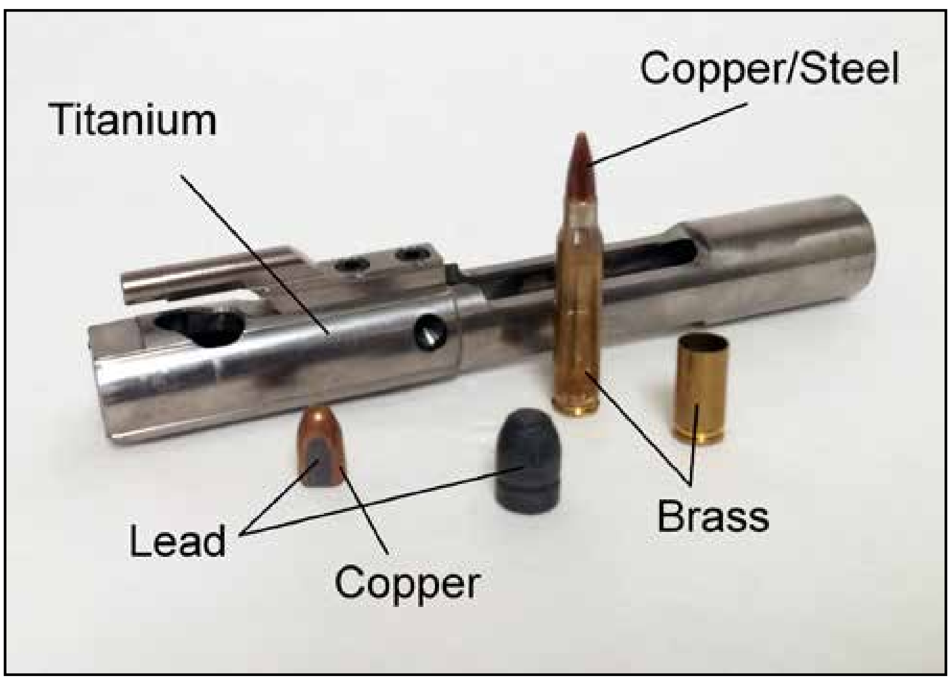


Figure 4: Other metals used in firearms.

B hardness ranging from less than 56 to 91.5, depending on the specific formula. Ultimate tensile strength: <39,000 – 91,000 psi. Yield strength: <23,000 – >88,000 psi.

Bronze – Bronze is also an alloy of copper. The primary alloying element in bronze is tin. Bronze is widely used in high wear or friction points in firearms. Depending on the alloy, bronze can be tailored for stiffness, ductility, machinability, and wear resistance. High aluminum bronze is often used in bushings (bearing surfaces) because of its excellent wear characteristics. Aluminum bronze can be hardened to Rockwell B 91. Ultimate tensile strength: 78,300 psi. Yield strength 58,000 psi.

Copper – Copper is a chemical element. It is a soft, ductile, malleable metal with high thermal conductivity and its use in firearms is primarily in the bullets. Bullets may either use a copper envelope (jacket) or be composed entirely of copper. Copper was introduced to bullets in the late 19th century as a need for a protective layer intended to be used in semi-automatic rifles. Traditional lead bullets were soft and could not withstand the process of an auto-loading action without deforming and causing malfunctions. Other added benefits of the copper jacket were that an increase in velocity was now achievable without worrying about bullet deposits fouling the barrel, and damage to the bore was prevented when steel core or armor piercing bullets were used. Copper has a Rockwell B hardness of 40 – 45. Ultimate tensile strength: 25,000 – 32,000 psi. Yield strength: 9,000 – 10,000 psi.

Hard Chrome – Hard chrome is a generic term for a coating of chromium on a material's surface. Hard chrome is used to reduce friction and improve durability through abrasion and wear resistance. It also minimizes galling or seizing of parts and expands chemical inertness to include a broader set of conditions. Hard chrome is indeed fairly hard, with a Rockwell C rating of 69. It is typically applied in thicknesses ranging from .005 in. to .020 in. and is typically reserved for rifle bores and as a decorative finish.

Inconel® – Inconel is an alloy of nickel. It is a nickel-chromium alloy considered a super alloy. Inconel is used in extreme heat environments, like gas tubes and suppressor baffles. It is extremely corrosion-resistant and forms a protective oxidation layer at high temperatures, retaining much of its strength over a wide range of temperatures. The cost of Inconel parts is often high compared to similar parts of different materials. Inconel features a Rockwell B hardness from 90 to 100. Ultimate tensile strength: 120,000 – 160,000 psi. Yield strength: 60,000 – 111,000 psi.

Lead – Lead is a chemical element and is a soft, malleable, heavy (dense) metal. It is the heaviest element that is not classified as radioactive. It is found primarily in bullets, but may be used as weights. Lead is the preferred material for bullet cores because of its density. Energy is a product of mass and velocity. Because firearms are limited to bullet size based on their bore diameter, the only way to introduce mass to a projectile is to make it out of a dense material like lead. Lead is also used to add weight to a firearm, making it more stable under recoil (the recoil force is dissipated by the weight). Lead is also extremely toxic. Make sure to wear gloves and never touch your face or mouth after handling lead bullets or weights.

Magnesium – Magnesium is a chemical element and is an extremely light metal that is two-thirds the density of aluminum while retaining a good amount of strength. Magnesium tends to be fairly soft and often requires alloying for use as gun parts. Its alloys are typically used in noncritical components where weight is a consideration. Magnesium has even been used to make AR platform receivers that are both light and strong. Magnesium can be hardened to <50 Rockwell B. Ultimate tensile strength: 35,000 psi. Yield strength: 17,500 psi.

Nickel – Nickel is a chemical element and is a hard and ductile metal. It is mostly used as a protective and cosmetic coating in firearms and cartridges. Nickel is often applied as a coating on gun parts because of its corrosion and abrasion resistance and is also used as an alloying element in many other materials used on guns. Nickel has a Rockwell B hardness ranging from 45 to 98. Ultimate tensile strength: 55,000 – 145,000 psi. Yield strength: 15,000 – 135,000 psi.

Titanium – Titanium is a chemical element. It is a low-density, high-strength metal that is extremely heat-resistant. In most instances, titanium is as strong as steel, but much lighter. Titanium is used to upgrade moving parts or guns (bolt carrier or firing pin) to increase the speed of cycling or lock time. It is about 60% as dense as aluminum while being more than twice as strong as 6061. One downside to titanium is that it becomes weak at temperatures above 800° F. Some titanium alloys achieve tensile strengths as high as 200,000 psi. Titanium is hardenable from Rockwell B 79 to 99. Ultimate tensile strength: 44,000 – 142,000 psi. Yield strength: 25,000 – 131,000 psi.

OTHER MATERIALS

There are many other materials used in the construction of firearms, including parts like frames and receivers, fire control parts, stocks, and other furniture. Modern day technology and material science has created materials that outperform many traditional materials used in firearms. Many of these materials were designed to be high performance replacements for common materials.

Composite – Composite is a generic term for a material that is composed of two or more dissimilar components and that features characteristics that differ from its base materials. A composite has two main parts: matrix and reinforcement. The matrix material (typically an epoxy or other resin) is used to secure the reinforcement material's (glass or carbon fiber) relative position, while the reinforcement material enhances the overall strength of the matrix. Composites used in firearms include components such as carbon fiber, fiberglass, Kevlar, and epoxy or polymer. Most composites used in firearms are in stocks and other furniture. Some receivers and frames even use composites in their construction. A popular

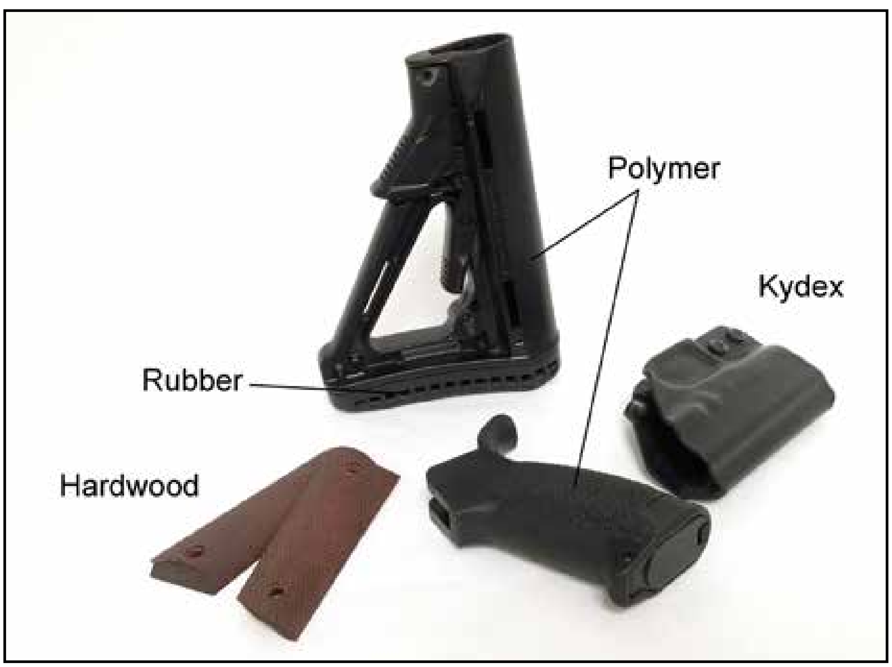


Figure 5: Other materials.

Figure 6: A Kydex holster.

use of composites also includes reinforcing rifle barrels. Super composites like carbon fiber may be up to 2X stronger than some steels by weight. This means of two similar parts weighing the same, the carbon fiber part may be up to twice as strong. If the same part was manufactured to be as strong as a similar metal part, the composite part would weigh much less. Composite materials also have many other advantageous characteristics, such as thermal conductivity (will help dissipate heat) and high energy dampening effect (will dampen barrel harmonics, making them stiffer and, in turn, more precise). The downside to composites using certain epoxies is that they are not UV-resistant and will degrade over time. Some composites are also fairly brittle, will not withstand impact, and the matrix and reinforcement may separate (delaminate). Tensile strength ranges by material makeup but can be as high as 18,000+ psi.

Fiber Reinforced Polymer (FRP) – A type of composite that uses polymer as its matrix and some type of fiber (carbon, glass or Kevlar) for its reinforcement. The type of reinforcement used can range from cut strands to ground fiber. FRP's are often injection-molded because the matrix is some form of polymer and this is the typical forming method for polymers. FRPs are often stronger than the polymer matrix alone and are preferred because of their enhanced mechanical properties. FRPs are found mostly in stocks and other furniture but are becoming more widely used in frames and receivers. FRPs also suffer from the same drawbacks as other composites.

Kydex® – Kydex is a type of thermoformed polymer, which is formed under the presence of heat. Kydex is found in varying thicknesses (.0625 in. – .250 in.) of flat sheet. It is widely used as holster and sheath material and is also found in forearm and stock covers or cheek risers. Under heat, Kydex becomes very malleable and will take the shape of molds extremely well. This makes Kydex a perfect material for holsters, as it will allow the holster to fit every contour of the pistol's form, providing high levels of retention. Kydex is also fairly easy to work with, making it a popular material for the home hobbyist.

Hardwood – Hardwood is a type of wood with a semi-uniform, dense fiber composition. Popular hardwoods used in stocks and grips and other furniture include walnut, maple and myrtle.

Hardwood is a preferred material because of its appearance. Fine hardwoods, like walnut, feature a visually appealing figure (grain) that is unique to every stock made. Hardwood used in stocks must be properly dried and stabilized before use. Working with some hardwoods may cause eye, nose, and skin irritation from exposure to wood dust. If not properly sealed, hardwood is also susceptible to moisture warpage. Hardwood can be categorized by its grade. Grades range from economy (straight, plain grain with minor defects) to exhibition grade (full figure and color along the entire length of the stock; exceptional in every way). Depending on the grade of wood, it can range in price from midrange to extremely high.

Figure 7: Bolivian rosewood hardwood 1911 grips.

Laminate – Laminate is a type of composite that features wood as a reinforcement and resin or glue as a matrix. The wood used in laminate is typically birch and the resin used is typically some type of epoxy. Laminates are often far superior to hardwoods in the respect they are not susceptible to warpage from moisture and do not feature inconsistencies like knots or other inclusions. Layers of laminate may also be dyed various colors, producing many colorful patterns in stocks and other furniture. One downside to laminate, like any other composite, is that it is prone to splitting (delamination). Laminate tends to be more cost-effective than hardwood.

Polymer – Polymer is a generic term for different forms of plastic. Polymers range from fully synthetic to semi-organic materials that offer a vast array of mechanical properties. Polymers

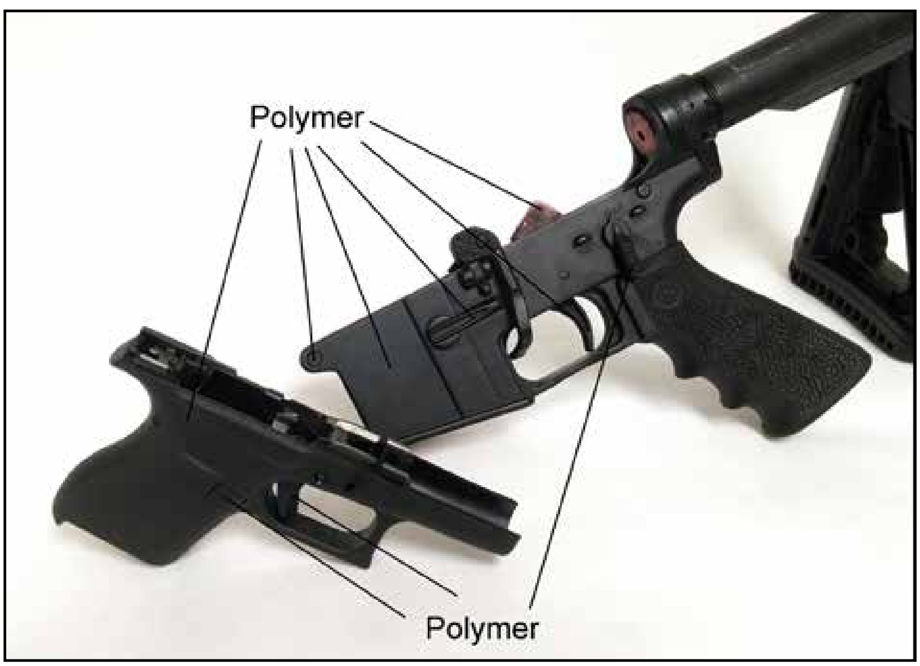


Figure 8: Polymer parts.

Figure 9: Rubber parts.

are often dense, while still being light, hard or soft, corrosion- and chemical-resistant, and easily formable. Polymers may also be mixed with dissimilar materials, making composites with greater material properties. Polymer has increasingly replaced many popular materials such as wood, stone, horn and bone, leather, paper, metal, glass, and ceramic. Popular polymers include Bakelite (first commercial plastic), polystyrene, and nylon. Polymer use in firearms is constantly growing and includes frames and receivers, fire control parts (triggers and hammers), stocks and furniture, many other small parts and controls, and is now even in the bullets and cases of cartridges.

Rubber – Rubber is a naturally occurring material that is soft and extremely flexible. Rubber is used in firearm grips, buttpads and other furniture. It is a preferred material because of two main reasons: tackiness and dampening. The inherent tackiness of rubber is perfect for grips, providing more control over the firearm. The dampening effects of rubber will also reduce the amount of felt recoil. Because rubber is so soft, it will absorb the recoil forces, making the firearm more comfortable to shoot.

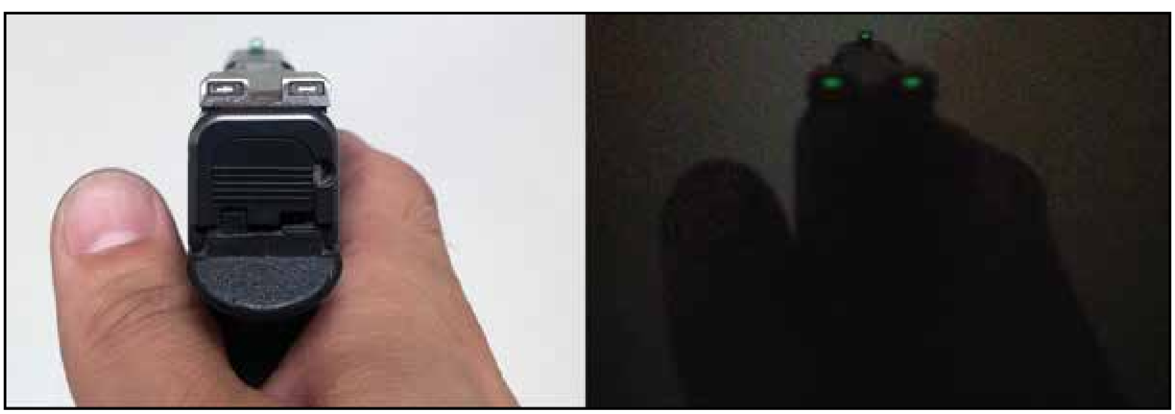


Figure 10: Tritium sights.

Tritium – A radioactive gas, tritium is an isotope of hydrogen. An isotope is a chemical element that shares the same number of protons with its parent element but a different number of neutrons. The occurrence of tritium is very rare on earth, with only trace amounts being formed with the interaction of atmosphere and cosmic rays. Tritium production occurs in nuclear reactors when lithium neutrons are radiated. Tritium gas by itself does not emit light, but when combined with phosphor, it will interact and create fluorescent light. Tritium is commonly contained in small phosphor-coated tubes used for night sights.

Attributes

Knowing what materials are used in firearms is only one piece of the puzzle. You must also know which of these materials are beneficial and which ones should be avoided. The following is a list of attributes you should be aware of when selecting certain materials for use in firearms.

Brinell, Rockwell, and Vickers Scales – The Brinell, Rockwell, and Vickers hardness scales are all based on standardized testing used to test the indentation hardness of materials. All three scales use some form of indenter and varying loads, but that's where the similarities end. The Brinell test was the first standardized and widely used hardness test. The typical Brinell test uses 1mm, 2.5mm, 5mm, and 10 mm steel ball(s) at 1 – 3,000 KGF (kilogram force). For softer materials, less force is used; for harder materials, a tungsten carbide ball is used. The hardness is calculated using a formula based on applied force, diameter of the indenter, and diameter of the indention.

The Rockwell test uses seven different scales (A, B, C, D, E, F, G), three different indenters, 1⁄16 in. steel ball (B, F, G), 1⁄8 in. steel ball (E), a 120° conical diamond (A, C, D), and two different loads of force. The first load of 10 KGF is meant to establish a zero (point of measurement), and the following load is from 60 (A, F) to 100 (B, D, E) to 150 (C, G) KGF. The indenter is then returned to zero. The depth of the indentation is measured by the machine and a dial indicates hardness. The advantage of the Rockwell test is that figures are provided instantly.

The Vickers test uses a single 136° diamond pyramid indenter (for all materials) at varying loads from 5 to 120 KGF. The diagonals of the indentation are measured to calculate hardness. Vickers values are calculated by the ratio of force applied and the area of the indentation. The Vickers test is often easier to use than other hardness tests because the required calculations are independent of the size of the indenter.

Brittleness – Brittle materials will fail under stress with no deformation. Brittleness is the exact opposite of malleable and ductile. When a material reaches the limit of its strength, it will either break or deform. Brittle materials will simply break like a piece of glass. Brittleness is often associated with hardness because as hardness increases, so does brittleness. With firearms, brittleness is a very unfavorable attribute that can lead to material failures and parts damage.

Compressive Strength – The ability of a material to be able to withstand crushing or compressive forces without permanent deformation or failure. Compressive strength is the opposite of tensile strength because instead of the forces trying to elongate or pull the material apart, compressive forces are trying to compress the material, in turn making it smaller. Parts of firearms that experience compressive forces are bolt faces/breechblock parts designed for impact. A material's ultimate compressive strength is often much higher than its ultimate tensile strength.

Ductility – The ability of a material to distort under tensile stress to the threshold of plastic deformation. Ductility is important to metals that are used to contain pressure, such as barrels. If the barrel was hard or brittle, it would fracture under strain. Ductility is also important to cartridge cases that must expand and stretch during discharge. If these cases were composed of a material that did not exhibit ductility, they would fracture in the chamber, creating a potentially hazardous scenario.

Elastic Deformation – The ability of a material to spring back to its original shape and dimensions after the application of force or strain. Elastic deformation is what makes a brass cartridge case return to (nearly) its unfired dimensions and be reliably extracted. Beyond the threshold of a material's elastic deformation, it reaches its yield and starts to exhibit plastic deformation.

Hardness – The ability of a material to resist permanent shape change when compressive force is applied. There are three main types of hardness measurements: scratch, indentation, and rebound. Scratch hardness is the measure of a material's resistance to being scratched. Indentation hardness is the measure of a material's resistance to deformation due to compressive forces. Rebound hardness is the measure of a material's ability to bounce back to its original size and shape after force is applied. There are also three major hardness scales, all based on indentation hardness: Vickers, Brinell, and Rockwell. Hardness is dependent on ductility, elastic stiffness, plasticity, strain, strength, toughness.

Machinability – Machinability refers to the ability of a given metal to be cut and removed, achieving a satisfactory cost. Metals that are said to have good machinability will require little force and cut fast, easily obtain a good surface finish, and place little wear on tooling. The same alloys and treatments that make metal harder and tougher degrade its machinability.

Malleability – The ability of metal to deform under compressive forces. If a material is malleable, it can be hammered or rolled into flat sheets or other shapes without breaking. Malleability is an attribute often associated with soft metals like gold, silver, and lead.

Plastic Deformation – A type of material deformation that is permanent. Unlike elastic deformation, where the material deformation is temporary, plastic deformation is typically a result of work hardening. Most materials undergo a degree of elastic deformation before reaching their yield and encountering plastic deformation.

Shear Strength – The maximum stress that a material can withstand under shearing forces. The simplest example of shear force is when paper is cut with scissors. Shear forces occur as opposing forces are applied to opposing sides of the material, causing the material between the forces to slide against each other. Parts that experience shear loads would include recoil lugs and takedown pins.

Tensile Strength – The maximum stress that a material can withstand while being pulled or stretched without failing or breaking. Materials that are more ductile will stretch under tensile stress, while materials that are harder/stiffer will fracture sharply (glass-like) without any deformation. Tensile strength is an important factor when reloading cases. Brass cases will be stretched multiple times from repetitive discharging and reloading. Cases will reach their ultimate tensile strength before a failure, such as a head separation or ruptured case.

Weldability – Weldability refers to a material's ability to be welded. Many metals are weldable but vary in difficulty based on alloying elements, treatments, and manufacturing processes. All materials are joinable with the correct bonding type. The material makeup will also dictate the welding or joining process used: arc, oxy acetylene, electron beam and resistance welding, brazing, soldering and adhesive bonding. Weldability is also known as joinability.

Yield Strength – The stress point at which a material starts to deform plastically. Before reaching its yield point, the material will deform elastically, returning to its original shape after the stress has been removed. The introduction of work hardening can greatly increase a material's yield strength. The harder material will require more stress to reach the yield point.

FORMING PROCESSES

Forming is also an integral piece of a firearm part's intended use and overall performance. Using an improper forming process can result in material inconsistencies that could lead to parts wear and breakage. Because of certain material properties, some materials can only be formed one way. The following is a list of the most popular forming processes.

Billet – A billet is a length of metal that has a round or square cross-section, with an area no more than 36 in.^{2} (230 cm^2). Billets are created directly via continuous casting or extrusion and are further processed via profile rolling and drawing. Final products include bar stock and blocks that are used to machine frames and receivers and other small parts. Parts that are cut from billet blocks are typically much stronger than cast parts and feature fewer material inconsistencies.

Brazing – A type of soldering. Brazing uses a copper alloy, typically brass, to attach sights or lugs to firearm barrels.

Casting – Casting is a forming process that uses a mold that is filled with a liquid material. When the material hardens, the mold is removed, revealing the intended part. Castings are typically done with molten metal, but other materials like epoxies and ceramics may be used. One main advantage of casting is the ability to create uniquely shaped parts. Cast parts are typically not as strong as parts machined from billet.

Forging – A manufacturing process that uses compressive forces to shape metal. Forging can be classified by the temperature at which it is processed: hot, warm, or cold. Forged parts are usually stronger and lighter than similar parts that have been cast. Forging is one of the oldest metalworking processes, typically performed with a hammer and anvil.

Extrusion – The process of creating billets with a unique cross-section. Extrusions are formed when a material is forced through a die of the desired cross-section. The main advantages of extrusion forming are the ability to create unique, complicated cross-sections and being able to work brittle materials. The extrusion process can be performed hot or cold (room temperature). Extrusion also forms parts with exceptional surface finish. Firearms parts that are extruded are handguards.

Hammer Forging – A barrel manufacturing process where an oversized blank is formed around a mandrel. The mandrel will feature a male pattern of the rifling on its exterior. Pneumatic hammers pound the cold barrel blank around the mandrel, forming the rifling and providing a very smooth, uniform bore surface and a very strong barrel. Barrels are very hard and wear-resistant because of the introduction of work hardening. The forging process introduces lots of stresses to the metal that, if not properly relieved, will result in poor harmonics and diminished accuracy and precision compared to a barrel that is not hammer forged. Hammer forged barrels are almost always chrome lined.

Injection Molding/Metal Injection Molding (MIM) – A manufacturing process where metal is injected (forced) into a mold. Many different materials can be injection molded, including metals, glass, elastomers, and, most commonly, thermoplastic and thermosetting polymers. Parts designed to be injection molded must take into account the material used for the part, the desired shape and features of the part, the material of the mold, and the properties of the molding machine.

Metal injection molding is similar to the injection molding process except a powdered metal/binder (wax or polymer) mixture is used. After molding, the part is either submerged in chemicals or is heated to remove the binder material. After the binder is removed, the part is baked at high temperatures that cause the powdered metal to fuse together, forming the part. Many metal and plastic firearm parts are injection molded, including stocks and furniture (plastic), hammers, triggers, and other small parts (metal).

Soldering – Soldering is the process of joining two metal parts together with a filler material. Soldering differs from welding in that the base metal is never melted or joined, only the filler (solder) is melted and joined. The solder features a much lower melting temperature than

the metals it is intended to join. Soldering is a preferred method for joining dissimilar metals that cannot be welded. It is often used to attach sights and side-by-side shotgun barrels.

Swage – A form of forging in which the piece is shaped by forcing material into a die. Swaging is usually a cold forming process but sometimes may be done hot. Swaging bullets produces a more precise piece than casting, so most major bullet manufacturers use swaging to produce their bullets.

TREATMENTS

Material treatments are used to change the mechanical properties of the material. These treatments make the material harder or softer or change the surface of the material or coat it with a protective layer. A certain material may use several of the following treatments to achieve a desired result.

Age Hardening – A type of heat treatment for aluminum, magnesium, nickel, titanium, and stainless steel, exposing the material to high heat. Depending on the amount of heat, age hardening can alter certain properties of the metal, creating fine particles called precipitates. These precipitates can vary in size and affect the metal in different ways. Think of precipitates like moisture particles in the air that turn into clouds and rain. The precipitates act as reinforcements to stop the movement of dislocations (material irregularities) in the material's atomic structure. Dislocations and impurities are often the biggest contributor to plasticity. Stopping this movement provides very high yield strength due to increased ductility because of its improved crystalline structure. It is referred to as aging due to its prolonged exposure to high and intermediate heat. Also known as precipitation hardening.

Anodizing – Anodizing is a process that creates a protective layer of oxide on some metals. The anodizing process consists of an electrical circuit that is comprised of the part (anode/positive electrode), an electrolytic (conducts electricity) solution (typically a water/salt solution or sulfuric acid), a cathode (negative electrode), and a current generator. The layer of oxidation is meant to provide the metal with both corrosion and wear resistance. The layer of oxidation

Figure 11: Anodizing.

Figure 12: Bluing.

can be tailored for thickness as well as be dyed for cosmetic effects. Aluminum, titanium, and magnesium can all be anodized. Almost all aluminum parts used on firearms are anodized.

Anneal/Annealing – A process of softening metal with the application of heat. Annealing is used on cartridge cases to make them more malleable and less brittle and is needed for repeated resizing and firing. Spot annealing is sometimes used to drill and tap a receiver for optics mounting. Normalizing is a form of annealing used on low carbon steels and creates a more uniform, fine-grain atomic structure, making it less brittle.

Bluing/Blueing – A treatment that oxidizes a thin surface layer on ferrous metals and produces a dark blue, black finish. There are many methods of bluing from hot to cold and many different chemicals used. Bluing does provide some corrosion resistance but is considered mostly an aesthetic finish. Bluing also features poor wear characteristics.

Case Hardening – A hardening process that uses heat to introduce carbon into the surface of iron-based alloys. Case hardening creates a thin, very hard, wear-resistant skin. The heat treatment may also color the surface with rich colors in shades of yellow, brown, blue, and gray, and is referred to as "color case hardening." The process sometimes involves the use of dangerous cyanide compounds.

Cryogenic Treatment (Cryo) – A cold treatment process that, with the introduction of nitrogen, slowly exposes the material to temperatures around -300° Fahrenheit. The extreme cold acts as a forge, compressing, aligning, and changing the structure of the material on a molecular level. The improved material structure relieves stresses and yields higher tensile and ductile strength, toughness, durability and a more uniform surface. Typical results of treatment on a barrel will include prolonged parts life and less breakage, less friction, easier cleaning, higher velocities, and increased precision.

Ferritic Nitrocarburizing – A case hardening treatment that diffuses nitrogen and carbon into the surface of ferrous metals. The diffusion process is accomplished at temperatures near 1,100°F. Nitrogen and carbon are introduced one of four ways: gas, plasma, salt bath, or pressurized fluid inside a vessel. This process creates a very hard, wear-resistant surface. Also known as nitriding, or by its many trade names: Melonite, Tenifer, Isonite, WASP, NiCorr, and others.

Heat Treatment – A metalworking process that is used to change the physical and sometimes chemical properties of the material. Heat-treating is done to achieve either a harder or softer material. Heat treatment processes include annealing, case hardening, precipitation hardening, tempering, and quenching. Low temperature or cold treatments like cryogenic processing are also forms of heat treatment.

Nickel Plating – The process of depositing a nickel or nickel alloy layer onto a base metal. Nickel plating is performed in one of two ways: electroplating and electroless plating. Nickel plating is used to provide a very durable corrosion-resistant layer used to protect the base metal (iron, steel, copper, brass, and aluminum). Electroplating, as its name implies, uses electric current to bond nickel and other elements to metal surfaces. Like anodizing, the part acts as the anode is immersed in an electrolytic solution. A nickel cathode is used, and when current is applied, the nickel begins to atomize and is attracted to the anode and bonding.

Electroless plating, like its name implies, does not involve electric current. Electroless nickel relies on a chemical reaction to deposit nickel onto the part's surface. The addition of other chemicals can enhance the mechanical properties of the nickel plating, making it more abrasion-resistant or lubricious. Some popular nickel coatings include nickel boron and NP3. Nickel boron is an electroless process that includes the addition of boron. NP3 is also an electroless process, but instead of boron, it relies on Teflon™ for its friction reduction characteristics.

Parkerizing – A coating for steel and other metals that uses phosphoric acid and phosphate salts to convert the surface to crystalline phosphates. The new surface provides corrosion resistance as well as lubricity and a suitable surface for paint or other coatings.

Physical Vapor Deposition (PVD) – A process of coating a metal with a ceramic-like metal coating. PVD coating is a type of electroplating process but differs from anodizing and nickel plating in the respect that it is done under vacuum and not in an electrolytic bath. With PVD, the part is the anode and a target (metal ingot) is the cathode. The target is vaporized in a variety of ways including heat, electricity, lasers, plasma, and electron bombardment. The vaporized material is attracted to the anode and deposits on its surface. The temperatures involved in the process are high enough to fuse the atomized coating, creating a uniform coating. The coating that is applied to the part will vary with the type of deposition used and the elements involved. PVD coatings are often harder and more corrosion-resistant than most other coatings. Most PVD coatings have high temperature and good impact strength, excellent abrasion resistance, and are so durable that protective topcoats are almost never necessary. PVD coatings can also be tailored to reduce friction. Most PVD coatings have a lower coefficient of friction than other coatings (while still being corrosion- and wear-resistant). Popular PVD coatings are TiN (Titanium Nitride), AlTiN (Aluminum Titanium Nitride), and DLC (Diamond Like Carbon). Because of the wide range of mechanical properties PVD coatings offer, they are

quickly becoming one of the most widely used in the firearms industry.

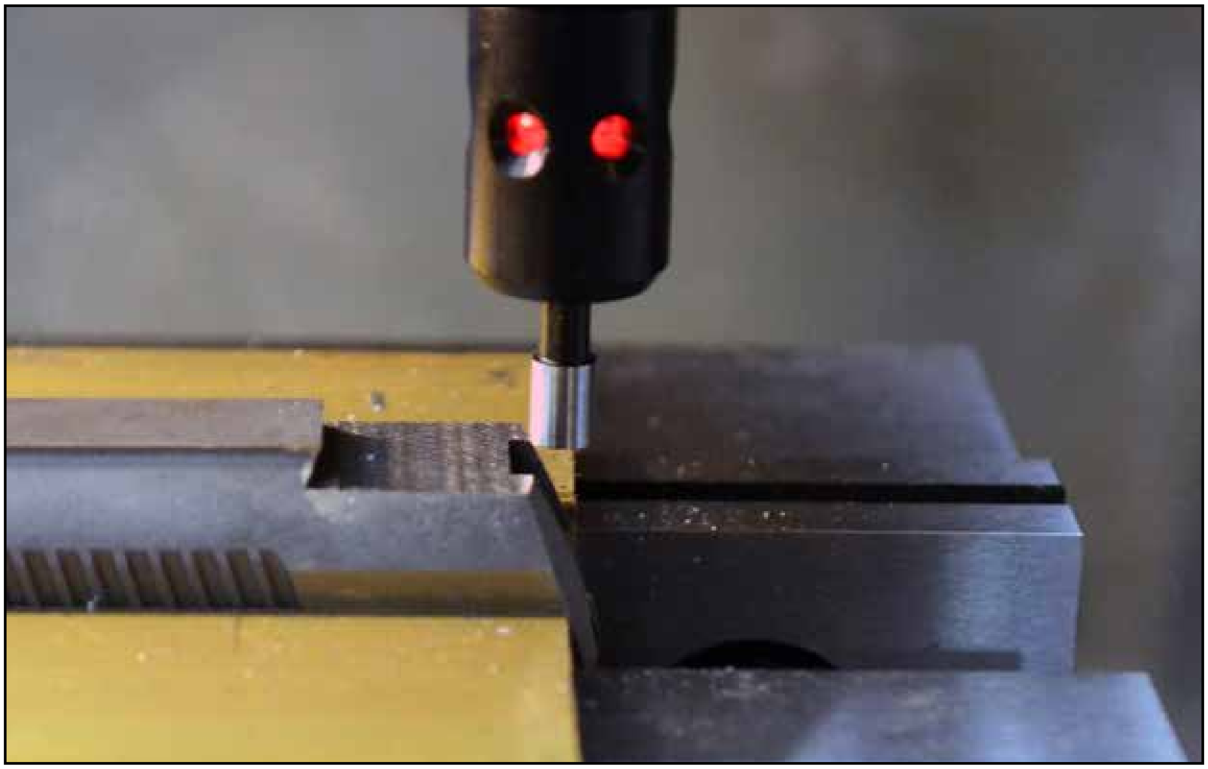
Quenching – The rapid cooling of hot metal to obtain certain material properties such as hardness. It is used to harden the surface of the material or throughout it by changing its material structure. Quenching is accomplished by heating the material to a specific temperature and then rapidly cooling it by immersing it in water, oil, or brine (saltwater).

Tempering – A heat treatment process that is used on ferrous metals such as steel. Tempering is performed after hardening to increase its tensile strength by reducing some of its hardness. Tempering is done at a much lower temperature than the hardening process and is used to fuse the crystalline structure of the metal, making it more ductile and elastic and less brittle.

Work Harden – A condition that occurs when certain metals or alloys and some polymers are strengthened or hardened through fabrication or machining processes. Work hardening occurs when a piece is subjected to external forces that cause dislocations in the material's structure, making it harder, but also removing some of its ability for elastic deformation. Removing some of the material's elasticity introduces plastic deformation, which prevents the material from partially returning to its original shape. Work hardening can be a good or bad thing, depending on application. It can be desirable in situations where wear or hardness is concerned. Work hardening of a cartridge case will prevent the brass from springing back to nearly its original size. These harder, more brittle cases are prone to cracking because they do not exhibit good ductility. Sometimes, work hardening can be reversed and some of the ductility returned through annealing.

NOTES

Chapter 3 - The Milling Machine



Introduction to Machining

BASIC MACHINING

Learning basic machining can drastically expand the scope of work you perform as a gunsmith and the profitability of your business. Being able to make a part that only exists as a drawing or broken sample can make you very valuable to your business. Learning basic machining can also lead to a career in manufacturing.

Drilling, tapping, turning, facing and threading are all operations that can be easily accomplished with three common machines: drill press, mill, and lathe. Most quality machines

***Figure 1**: Clockwise – A drill press, mill, and lathe.*

with the appropriate fixtures, jigs, or tooling will be more than capable of handling most jobs and materials. With the appropriate equipment, it is possible to machine a complete firearm.

Please note that the procedures discussed in this section are standard operating procedures (SOP) for working with heavy machines. This guide is not intended to make you into a machinist, but to make sure you can perform certain tasks safely. This guide is intended to be the starting point on a long road of learning, training, and practice, all in preparation of owning or operating a machine/gunsmithing shop of your own.

Figure 2: It is important to follow certain safety guidelines when working with such powerful machines.

Safety Reminder

Every time you work with any heavy machine, make certain you follow these safety guidelines to ensure minimized risk for injury.

- **Safety Glasses**. Anytime you are working with heavy machines and cutting material, you should be wearing safety glasses. While performing machining on various materials, you run the risk of exposure to flying particulate, metal chips, and possibly shrapnel (if a part or tool breaks). You may also need a face shield, hearing protection, dust mask, or respirator.
- **Appropriate Attire**. Your attire may create a high risk for injury. Loose or baggy fitting clothing, long sleeves, untucked shirt, gloves, rings, watches, necklaces and other jewelry may become caught in the machine while it is running, potentially leading to serious injury. Make certain there is nothing hanging from your person that could become trapped in the machine while it is running.
- **Perimeter**. Create a perimeter around the machine. You want at least a 2 ft. perimeter around all machines so you and the workpiece have room to move freely around the machine.
- **Guards and Safeties**. Do not remove or disable any guard or safety on the machine. They are there for your protection.
- **Holding and Adjustments**. Tooling (bits and cutters) and parts should be securely held in place while the machine is running and any adjustments should be made with the machine turned off.
- **Always remember to remove and chuck keys, wrenches, and other tools from the machine before startup.** Make sure the machine is turned off before making any adjustments or taking any measurements. Never try to stop the machine by hand while it is running.

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Drilling

Drilling a hole is the oldest, most common, and probably the easiest, machine operation. Although you can drill a hole with a hand drill, you cannot get as precise of a hole other than with a drill press or mill; but for the purpose of this section we are focusing on the press. Drilling is easily accomplished when the correct bits are used for the selected material, but can be very difficult with the wrong bits. Most beginners believe it is easy to simply drill a clean, concentric hole into a piece of material but often find out it is more difficult than they originally thought. This section will teach you how to set up, select the right tooling, and drill a straight, concentric hole in any material.

DRILL PRESS

The drill press is often the keystone piece of any machine or fabrication shop. A drill press with the correct bit and an array of vises and fixtures is capable of handling a majority of your fabrication needs. Because of the versatility of the drill press, you may use more than one in your shop: a smaller tabletop version for small or quick jobs and a larger standalone unit for larger jobs or production work.

Figure 3: Drilling a hole in a sight to install a set screw.

PARTS OF THE DRILL PRESS

Most drill presses feature the same basic parts that function in the same manner, regardless of make or model. Knowing the parts of your press will help you safely operate and diagnose any issues that may arise.

Figure 4: Standalone drill press.

Below is a list of parts for a basic drill press.

- **Motor**. The motor is the heart of the press and is used to drive the chuck through a series of pulleys or gears and spindles. The motor spins at one speed and produces a specific amount of power. The press relies on the speed control to slow or accelerate the speed of the spindle and chuck. A minimum of ¾ horsepower is recommended for use on small to medium holes in most metals, while 1 – 1.5 horsepower would be optimal. The motor may be hardwired to a power source or use a more convenient 3-prong cord.
- **Chuck**. The chuck is a specialty clamp designed to center and hold cylindrical objects like bits or other tooling. It uses a series of jaws (3 – 6) arranged symmetrically around the inside of the chuck. When the sleeve is turned around the body, the jaws will open and close, allowing you to secure and use different size bits. There are limitations to the size of bit most standard chucks can handle. Depending on the size of your machine,

Figure 5: Parts of a chuck.

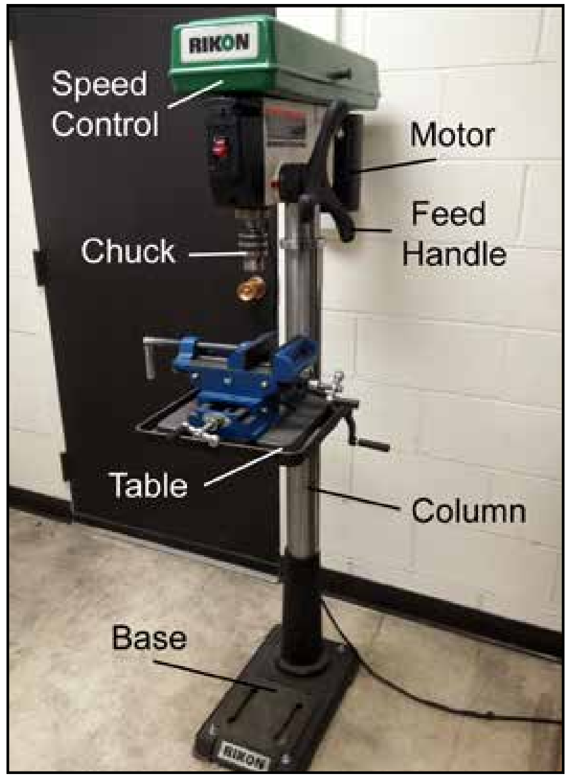

Figure 6: Parts of the drill press.

you may have a ¼, ½, ⅝ or ¾ chuck. The number refers to the maximum size bit the chuck will accept. A ½ chuck will hold most bit sizes you will be using, but there are adapters that will allow you to use bits that are larger or smaller than your chuck is capable of accepting.

- **Feed Handle.** The feed handle controls the vertical movement of the chuck and allows the operator to regulate the speed that the bit moves through the material. It has no effect on the speed at which the bit spins, but rather how fast the spinning bit moves up and down through the material. The feed handle is typically spring-loaded, always pushing the chuck up and away from the workpiece. The feed handle may also feature some type of stop that will limit the movement of the handle and the chuck. The stop will allow you to consistently drill to a specific depth.

  The speed at which the feed handle is operated is completely reliant on the material being cut and the type of tooling being used. When drilling soft materials like wood, plastic, or soft metals, you want to move faster than you would for hard metals. Regardless of the speed required, you do not want to put much pressure on the handle bit or workpiece.

- **Speed Control**. The speed control allows you to adjust the speed at which the chuck spins and lets you tailor your press to use a specific bit type in a specific material even though the motor only spins at one speed. Speed is controlled by a series of various sized pulleys and belts, chains or by gears. The advantage of gear-driven presses is that you can set the gear ratios to allow you to tap (thread) a hole.[1]

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[1] *Although the machine may be equipped to thread, for beginners it is still recommended to perform threading operations by hand.*

Refer to your owner's manual for specific settings for your particular model.

- **Table**. The table is used to hold your workpiece against while drilling. It may feature a hole directly in the center that is centered around the bit to prevent the bit from drilling into the table, and may also have holes or slots for mounting various press or machinists' vises. The table may also be adjustable for different angles and heights.
- **Column**. The column is like the spine of the drill press: it is the main support for the head and the table. The column supports the toothed elevator that allows the table to move up and down.
- **Base**. The base is the foundation of the press and is used to support and secure the machine. The base also serves as a mounting point for the press. The stability of the base is important to the overall performance of the machine.
- **Through Drilling**. Through drilling is exactly what its name implies: drilling a hole completely through the workpiece. Through drilling some materials will require a backing piece under the workpiece to prevent chipping when the bit "breaks" through the bottom of the workpiece. Through drilling may also be used as a step before making a threaded hole.
- **Stop Drilling**. Stop drilling, as its name implies, is the process of drilling a hole that "stops" or bottoms out in the workpiece. Depending on the type of bit used, the bottom of the hole may be flat (reamer) or conical (twist drill). Stop drilling usually involves drilling a hole to a specific depth set by the drill stop on the press or a stop on the bit itself (Figure 7).
- **Reaming**. Reaming is the process of enlarging and refining an existing hole with a precision bit. It requires a preexisting hole or a hole to be drilled that is .010 in. – .015 in. smaller than the desired finished hole. Reaming will leave a clean, concentric hole with a flat bottom and can also cut precision tapered holes for pinning parts.
- **Angle Drilling**. Angle drilling is also as its name implies: drilling a hole (either stop or through) at an angle. Angle drilling can be accomplished in a variety of ways — either the head of the press, the table, or vise may be angled or the workpiece may be secured at an angle.

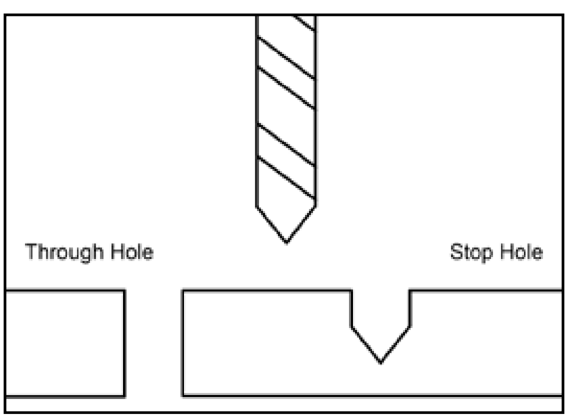

Figure 7: Through hole vs. stop hole.

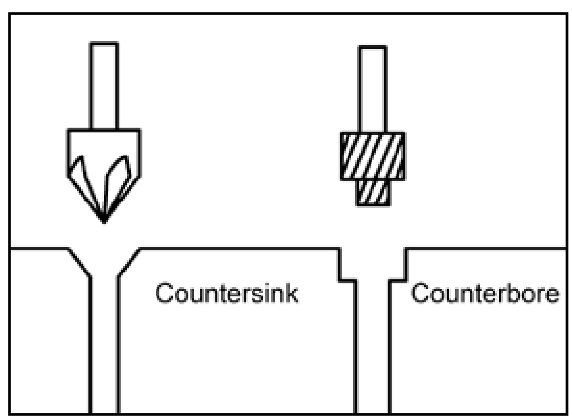

Figure 8: Countersink vs. counterbore.

Figure 9: *Grinding with a drill press.*

- **Countersinking/Counterboring**. Countersinking/boring is the process of profiling the opening of the hole for clearance, safety, or aesthetics. Countersinking/boring is often used to provide clearance for screw/bolt heads to sit at or below flush of the workpiece's surface. The difference between countersinking and counterboring is the profile of the clearance. The countersink will leave a conical relief while a counterbore will leave a rod-shaped, flat-bottomed relief (Figure 8).

- **Drilling Round Stock**. Drilling round stock is the process of drilling a hole (either through or stop) in a workpiece that is round or radiused, such as a rod or tube. It requires special fixturing to secure the tube or rod, called V-blocks. Drilling round stock can sometimes be very challenging and requires specialty equipment, such as a round stock center finder to locate the center of the workpiece. Also, certain bit types are preferred (spot over twist) because of the bit's tendency to "walk" over curved surfaces.

- **Jig Drilling**. Jig drilling is the process of drilling holes in a workpiece (either stop or through) while the workpiece is being held securely in a jig. The jig often features "guide" holes to properly align the bit with the exact location the hole must be drilled. Jig drilling is often used in high volume production work where tolerances are precise.

OTHER OPERATIONS

Outside of the operations described above, there are other operations that can be performed with a drill press. With specialty tooling it is possible to perform sanding, grinding, and jeweling on your workpiece.

- **Sanding/Grinding**. With the appropriate tooling, you can perform various sanding and grinding operations. By using a drill press milling vise and sanding drums and disks or various shaped grinding stones, it is possible to shape your workpiece in a variety of ways (Figure 9).

- **Engine Turning/Jeweling**. Engine turning or jeweling is an aesthetic process that leaves a series of swirls on the workpiece's surface for decoration that also holds lubricant and provides relief for debris. Jeweling is performed with wire brushes or abrasive rods that are used to scratch a swirl pattern onto the workpiece's surface (Figure 10).

Figure 10: *Jeweling on a drill press.*

GETTING STARTED

You may already own a drill press as a hobbyist or may be considering purchasing one; either way, there is often some assembly and setup required. Assembly of your press should always be by manufacturer's instructions; however, setup is usually based on your shop or space's requirements.

SETUP

Thoughtful planning before setting up your press will save you many headaches down the road. First is the location. You want to place your press in an area that will allow you to access the whole table and allow you to work on longer pieces without bumping into things. You also want to consider your power source. Is your location close enough to an outlet or will you need an extension cord?[2] Once you have your location, you will need to decide how to mount the press.

Tabletop presses may be mounted directly to the workbench or onto a separate base made of wood or metal. Standalone presses need to be mounted to the floor. Regardless of the type of press or mounting solution, you must be sure the machine is level and square.

Start by leveling the base. Most workshop floors tend to be fairly level, so this is usually as simple as mounting the base directly to the floor. If the floor is not level, you will need to shim the base. Make sure you level the base on both the X (side to side) and the Y (fore and aft) axis to ensure the column is square, plumb and level. Next you will need to square the table to the chuck.

Every hole you drill will not be "square," meaning 90° perpendicular to the workpiece; but squaring and leveling everything will make setting up your workpiece much easier later on. A table that is level and square to the chuck will give you a known variable when aligning your workpiece to the bit. Most tables have provisions for adjustment along both the X- and Y-axis to allow you to drill at various angles. Tables usually feature Z (up and down) adjustment, as well, to allow drilling into various sized workpieces. You may have to readjust your base so that your table, column, base, and chuck are all level, square, and plumb. Squaring the table to the chuck is also known as *tramming*.

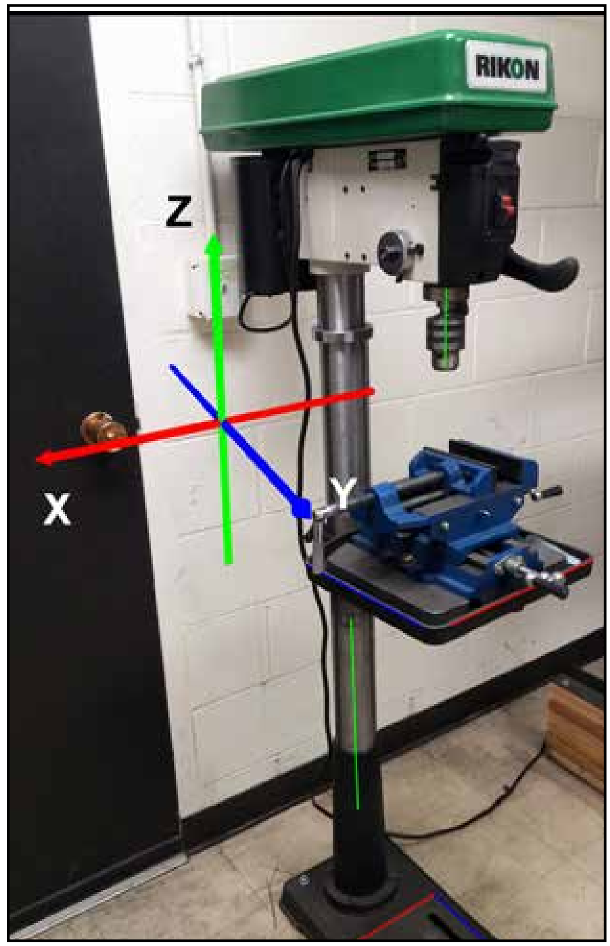

***Figure 11**: Setting up the press and the work area.*

[2] *Be aware you may also have to ground the motor to prevent damage or electric shock. Please refer to your owner's manual for instructions for your particular model.*

Figure 12: Locating the center point for your hole.

Before start up, make certain the press has been properly lubricated. Refer to your owner's manual for specific lube points. You may also consider wiping the table and column with a light coat of oil to prevent rust.

DRILLING

Now it's time to drill a hole. It seems like a simple task, but when performed correctly, the hole is the result of many carefully considered variables. Where is the hole going to be? What material are you drilling into? You should develop a mental or physical checklist of the steps involved in drilling a hole.

- **Location**. Planning out the location of your hole is one of the most important steps. Often, you only get one chance to drill the hole in the correct location, so there is no room for error; otherwise, you may find yourself buying replacement parts.

You will need a handful of tools and materials. Various calipers, rules, squares, combination squares, protractors, and levels, along with scribes, center punches, and layout dye, are all used to help locate the hole. The workpiece is first covered in a thin coat of layout dye[3] that is allowed to dry for several minutes. By using drawings or plans and known measurement of your workpiece, you can start to layout the location of your hole.

Use rules, squares, protractors, and scribes to "draw" the layout on the surface of the workpiece. You only need two measurements that intersect 90° to locate the center of a hole. Use the straight edge of the rules and squares to scribe your lines.

Once you have located the center of your hole using the intersecting lines you just laid out, you can use a center punch to

[3] *Layout dye may stain certain materials like wood, so test a sample piece.*

mark the starting location of the hole. You can use either a center punch and hammer or an automatic center punch; either way, take your time and make certain of your punch placement. This dimple that you create will center the tip of the bit when drilling begins; so if it is not precise, your hole will be off center.

- **Material**. Knowing your material is also a big part of drilling a hole properly. Nine out of ten times you can use any twist drill bit to drill a hole in your workpiece. On the tenth time, however, you may have to drill into hardened steel and your average high speed steel (HSS) bit may not be enough. Most modern twist drill bits have been specially developed for the material they are intended to be used on.

  Knowing your material will allow you to choose the bit that will work best for the job at hand. Once you have selected the bit that will work best, you can set the speed of your chuck. Most machines feature some means of speed adjustment, whether it be belts or gears or some other method. A good rule of thumb is you want the bit to be harder than the workpiece and to move as fast as necessary to provide a smooth, clean cut. Small diameter holes and soft materials usually require high rpm (revolutions per minute), while large diameter holes or hard materials use lower rpm. Cutting too slowly or too quickly will put excessive strain on the bit and workpiece and will leave a sloppy, burred, or chipped finish.

  It would be smart to have a machinists' handbook on hand in case there is ever a question of what type of bit to use at a given speed for a specific type of material. These handbooks can be very valuable to any machine shop as they contain figures for cutting speeds and feeds for various materials and types of bits, as well as other info valuable to machinists, engineers, draftsmen, and toolmakers.

Figure 13: Clamping your workpiece.

- **Securing**. You want to secure your tooling (bits) and workpiece while drilling to ensure the most precise, cleanest hole possible. Any movement of the tooling or workpiece while drilling will cause the hole to become oblong, or could potentially fling the workpiece across the room, which could be extremely dangerous.

  Securing the tooling is fairly simple. Make certain the tooling is centered in the jaws of the chuck. Turn the chuck until the bit is secure and centered in the jaws. Use a chuck key to further tighten the jaws around the bit. Do not over-tighten because you may strip the teeth on the chuck. Remove the chuck key before starting the machine.

  Usually a C-clamp and/or vise are all that is needed to secure the workpiece while drilling. Another option would be

a dedicated machinist's vise mounted to the table. The advantage of the machinist's vise is that it offers another degree of X and Y adjustment to ease setup. Some of these table-mounted vises may even rotate, adding another degree of adjustment and further easing setup. Please be cautious, though. Even though the machinist's vise allows for mill-like function, the chuck of the drill press was not designed to handle side load like a mill does. Using a drill press like a mill will surely damage your machine.

You want to clamp the workpiece hard enough to prevent it from moving while drilling, but not so hard that you mar the finish or crush the piece. You may need some type of support inside of hollow workpieces to prevent them from being crushed while clamping. You may also need some type of jig to hold some workpieces in a specific manner.

- **Lubrication/Coolant**. Some materials may require some type of lubrication or coolant. The lube or coolant serves two purposes. First it keeps the bit cool, which prolongs tool life and cutting surfaces. Second it aids in clearing chips from the hole. Every machinist has a lube or coolant he or she swears by. Cutting fluid is most commonly used, but motor oil, vegetable oil, or even dish soap may be used as substitutions.

There is another school of thought that using oil for cutting is counterintuitive. Because oil is used to make two surfaces slide against each other, they believe the bit will not cut as effectively as it will without lube. You may have to test certain combinations of materials, bits, and lubes to find what works best for you. Regardless of what you use, sharp tooling will always give you the best results.

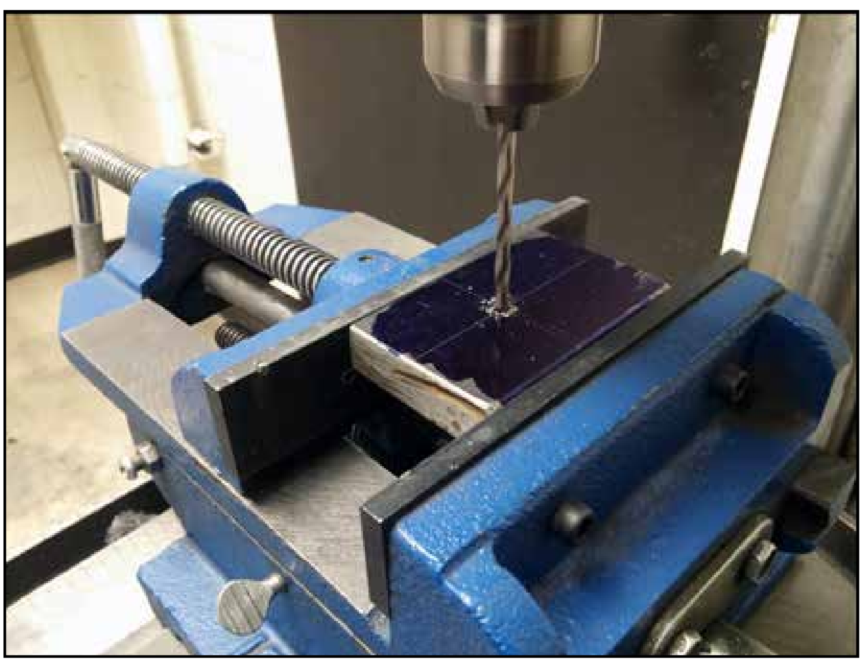

***Figure 14**: Drilling a hole.*

- **Safety**. You are almost ready to drill your hole, but first you need to do a last minute safety check. Make certain both your tooling and part are secure and the work area is clear of anything that may touch the bit or chuck while spinning. Also make sure the feed handle/lever is free from obstructions and that the chuck key was removed. Remember to check yourself for clothes, jewelry, gloves, or hair that may become caught in the machine. This is your last chance to prevent damage or injury, so be certain you go over your safety checklist. This may seem like you are being overly cautious, but it only takes a small lapse in judgment or procedure to lead to disaster.
- **Drilling**. It's finally time to drill a hole. By now you are realizing that the actual act of drilling the hole is only about 10% of the process while preparation is 90%. Turn the machine on and pull down on the feed lever until the bit almost touches the workpiece. Slowly touch the bit to the workpiece to begin cutting. Continue applying light pressure to the lever to continue drilling deeper until you reach your desired depth or drill completely through.[4]

For precision holes, you may want to start the hole with a spot drill bit, which will not walk like traditional twist drills. You may also want to drill your hole slightly undersized and ream the hole to the correct diameter. For larger holes, you should start with a smaller bit and work your way up to the final size. For deeper holes, make sure to back the bit out of the hole to clear any chips that build up.

With metals, your chips will reveal a lot about your setup and tooling. In a perfect world, you would have one long curling chip with no discoloration from the hole you drilled. This means that you would have selected a sharp bit made of the appropriate material for the appropriate material and that everything was moving at the correct speeds and nothing got hot. Small chips could mean your bit or feed is too fast or your bit is dull. Heat discoloration of your chips means your tooling is experiencing too much friction and getting too hot.

[4] *Make certain you set your depth stop before turning the machine on.*

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Bits, Vises, Clamps, Fixtures, Jigs, and Accessories

There are many tools and accessories that you can use to perform various operations with your drill press. Knowing what accessories are available will allow you to select the best tools for the job at hand.

BITS

There is a huge array of bits of different sizes, made from different materials for different materials that all serve to complete one specific purpose: cutting. Using the correct bit for your job will ensure the smoothest operation.

- **Twist Drill Bits**. Twist drill bits are the most commonly used bit for drilling holes. The twist drill bit consists of a pointed tip at the end of a round shaft, with helical flutes that run from the tip to the shank (the part grasped by the chuck). A twist drill bit can be categorized by a few characteristics: material, point and lip angle, flutes, and coatings.
  - **Material**. The material the bit is constructed from will dictate what materials it can cut. The most common bit materials are low carbon, high carbon, high speed steel (HSS), cobalt steel, and tungsten carbide.
    - **Low Carbon** – Inexpensive bit designed for wood. Soft cutting edge requires frequent resharpening.
    - **High Carbon** – More durable than low carbon because of hardening and tempering. Excessive heat will ruin the temper and lead to a soft point. Designed for wood and soft metal.
    - **HSS** – A type of tool steel that is much harder and heat-resistant than carbon steel. Designed to cut hardwoods, metal, and most other materials at a higher speed than high carbon steel.
    - **Cobalt** – A type of HSS that incorporates cobalt. The cobalt makes them remain hard at higher temperatures. Designed for stainless steel and other hard materials. The hardness of cobalt also makes it brittle.
    - **Tungsten** – A type of carbide (a metal with a molecular structure similar to a crystal). Hardest of all the bit types and fairly expensive, it is designed

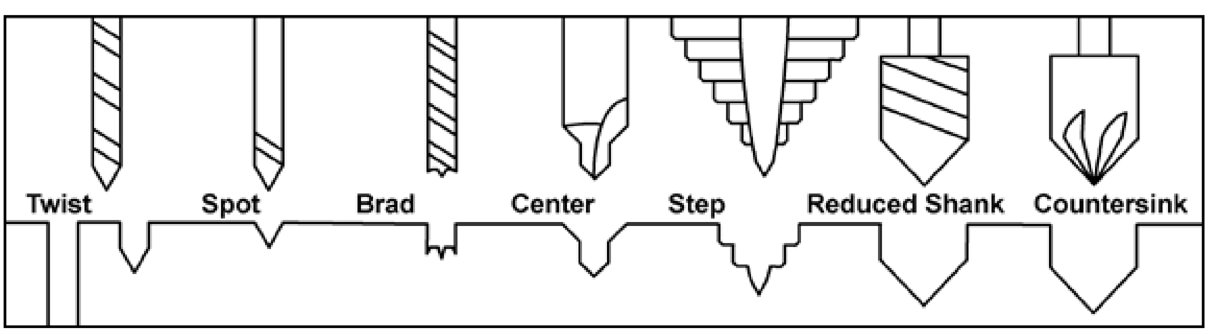

Figure 15: Different bits and their cut profile.

for any material. Tungsten carbide tends to be fairly brittle.

- **Point Angle** – The point angle will dictate how aggressively you can drill through a specific material. Harder materials will require a larger point angle (118° – 135°) while softer materials will require a sharper angle (60° – 90°).
- **Flutes** – The twist rate of the flutes controls material removal from the hole. A fast twist rate is designed to remove material faster for a faster feed rate. A slower twist rate is designed for softer metals where galling is concerned (aluminum or copper).
- **Coatings** – Coatings are used to protect bits and prolong their cutting life. Coatings include black oxide and various blends of titanium nitride (TiN, AlTiN, TiCN). Black oxide provides corrosion resistance as well as heat resistance and lubricity. TiN and its variants provide the same properties as black oxide, but with much greater performance (3X – 5X tool life).

- **Spot**. Spot drill bits are used to start a hole for a precision application. Spot drill bits are most commonly constructed of HSS and are very short, with little to no flutes. Spot drills are meant to be very hard and stiff to prevent "walking" when touching the workpiece. The spot drill will create a perfectly centered dimple used to guide a twist drill.
- **Brad Point**. Also known as the lip and spur bit. Brad points are specifically designed for drilling in wood. Because of the random grain pattern of wood, the misaligned fibers will cause the tip of a twist drill to walk in the hole and make it oblong. The center of the bit is a very sharp pyramid that continuously "center punches" the wood, keeping the bit aligned. Instead of cutting a hole from the center outward like with twist bits, the brad point cuts from the outside in.
- **Center**. Center drills combine a twist bit with a countersink. Center drills are used when a large diameter hole needs a starter hole, or to provide a lathe center. Screw pilot bits are similar to center bits, being a twist bit with a countersink/counterbore. Screw pilot bits are designed for use with wood.
- **Step**. Step drills feature a tip that is a lesser diameter than the rest of the cutting surface. The transition from lesser diameter to larger may either be tapered (forming a countersink) or straight (forming a counterbore). The step drill is used to cut a relief in the material for screws or bolts to sit at or below flush of the part's surface.
- **Reduced Shank**. Reduced shank bits feature a shank that is a lesser diameter than the flutes. The reduced shank bit allows you to drill a hole that is a larger diameter than your chuck is capable of handling.
- **Countersink/Counterbore** – The countersink and counterbore are profiled to provide a relief cut for screw and bolt heads. The countersink provides a taper clearance while the counterbore provides a straight-walled step clearance. A countersink may also be used to remove the burr from drilling and tapping.

VISES AND CLAMPS

Drill press vises are used to secure workpieces with different sizes and shapes. The vises themselves come in many sizes and shapes. Any vise that you use must be mounted to the table to remove any movement or "play" while drilling. Most vises are fairly simple and do not allow any adjustment.

A machinist's vise or "milling" vise allows adjustment along both the X (east and west) and Y (north and south) axis for an almost unlimited amount of adjustment. The greatest advantage of a milling vise is the ability to perfectly align your secured workpiece to your bit. A milling vise will allow you to rapidly secure and align many different sizes and shaped workpieces.

V-block clamps (Figure 16) will allow you to secure round parts such as tube or rod. V-blocks prevent round parts from turning while drilling. The V-blocks will still need to be secured by the vise before drilling. C-clamps may also be used, in a pinch, to secure workpieces to the table. It would even be possible to use various types of machinists' clamps with enough ingenuity.

***Figure 16**: A milling vise and V-block clamp.*

FIXTURES AND JIGS

Fixtures and jigs are used to hold workpieces consistently in a specific manner for multiples and production work. Fixtures and jigs allow the workpiece to sit in a specific position or angle while being easy to secure. Fixtures and jigs usually have a square (right angle) outside profile that makes locating and aligning workpieces as simple as leveling and squaring the block (Figure 17).

OTHER ACCESSORIES

- **Chuck Adapter**. A chuck adapter will allow you to use a larger bit than your machine is capable of accepting. The adapter looks like a second chuck with a shank that fits in a standard sized chuck.
- **Pin Vise**. A pin vise will allow you to use a smaller bit than your chuck is capable of accepting.

***Figure 17**: Drilling jig.*

- **Drill Stops**. Drill stops are collars that fit around the outside of the bit and limit its travel depth. The stops come in various sizes to fit several different sized bits. The stops are usually secured to the bits with a set screw.
- **V-Block Vise Jaws**. Vise jaw inserts that are used to secure round parts such as tubes or rods.
- **Lights**. The more light you can get on your workpiece, the better you can see what you are doing. There are many lighting options that can mount to your press's head or table.
- **Tool Tray**. Tool trays are invaluable when it comes to organizing your tooling or arranging it to be changed out quickly. Tool trays can hold everything you need to get the job done.

MAINTENANCE

Like any other machine with moving parts, there is a degree of maintenance to keep your press running smooth for a long time. Your owner's manual will guide you through the specific maintenance procedures for your machine. Two very common procedures are cleaning and lubricating the chuck and tensioning or replacing the drive belts. It may sound cliché, but if you take care of your equipment, your equipment will take care of you.

Figure 18: Oiling the chuck and adjusting the belts.

Milling

Milling may seem similar to drilling, but when you fully understand the capabilities of the milling machine, you will discover a world of possibilities. Milling machines can perform all of the same operations that a drill press can, with the added advantage of being able to cut sideways. A milling machine moves a rotating cutter into the workpiece and the workpiece around the cutter. A drill press is only capable of cutting in the Z-axis (vertical/up and down), while a mill can cut in 3 axes: X (side to side), Y (fore and aft), and Z. The advancement of technology has pushed milling to be the most popular machine operation.

MILL

With a wide range of adjustment and a plethora of bits and other tooling, the mill is capable of almost any machining job you will come across. The mill has evolved to the point that the average hobbyist can afford a smaller tabletop machine that is capable of tasks that a larger machine would perform. The introduction of computer control has turned the mill into a production workhorse. Powerful CNC (computerized numerical control) software and state-of-the-art 6-axis mills (XY and Z, as well as rotation of the table/part, rotation of the head around the part, and angling of the tooling), combined with auto-feed tooling, make producing the most intricate parts a breeze. You can now even buy tabletop CNC mills to use on small parts and soft materials.

The average gunsmithing shop does not require a CNC mill for everyday operations. A CNC mill would be better suited for a firearm manufacturing company where hundreds to thousands of guns are produced every year. The average gunsmithing shop would be better equipped with a vertical manual mill (motor and spindle are arranged vertically). There are also horizontal mills (motor and spindle are horizontal), but

***Figure 19**: Vertical manual mill.*

for the purpose of this section we will be focusing on the vertical mill. As chance may have it, the first mill was built by Eli Whitney for building muskets.

PARTS OF THE MILL

Most mills feature the same basic parts that function in the same manner, regardless of make or model. Knowing the parts of your press will help you safely operate and diagnose any issues that may arise.

Below is a list of parts for a basic mill.

- **Motor**. The motor is the heart of the mill. It is used to drive the spindle through a series of pulleys or gears. The motor may spin at varying speeds while producing a specific amount of power. The mill also uses the head/drive to slow or accelerate the speed of the spindle

even further. A minimum of 1.5 – 2 horsepower is recommended for milling operations in most metals, while 3 – 4 horsepower would be optimal. The motor may be hardwired to a power source or use a more convenient 3-prong 220 volt plug.

- **Head/Drive**. The head (drive) controls the speed at which the spindle/quill spins and lets you tailor your mill to use a specific bit type in a specific material. Speed is controlled by a series of various sized pulleys and belts or by gears. The advantage of gear-driven mills is that you can set the gear ratios to allow you to tap (thread) a hole.[5] Refer to your owner's manual for specific settings for your particular model.

  Spindle speed is controlled in two ways: by a crank and lever. Speeds are also divided into high and low ranges. The crank allows you to make fine adjustments to spindle speed while the machine is running. A dial on the head of the machine will give you an approximate speed reading. The speed adjustment lever will allow you to switch from high and low speed ranges. Lever adjustment must

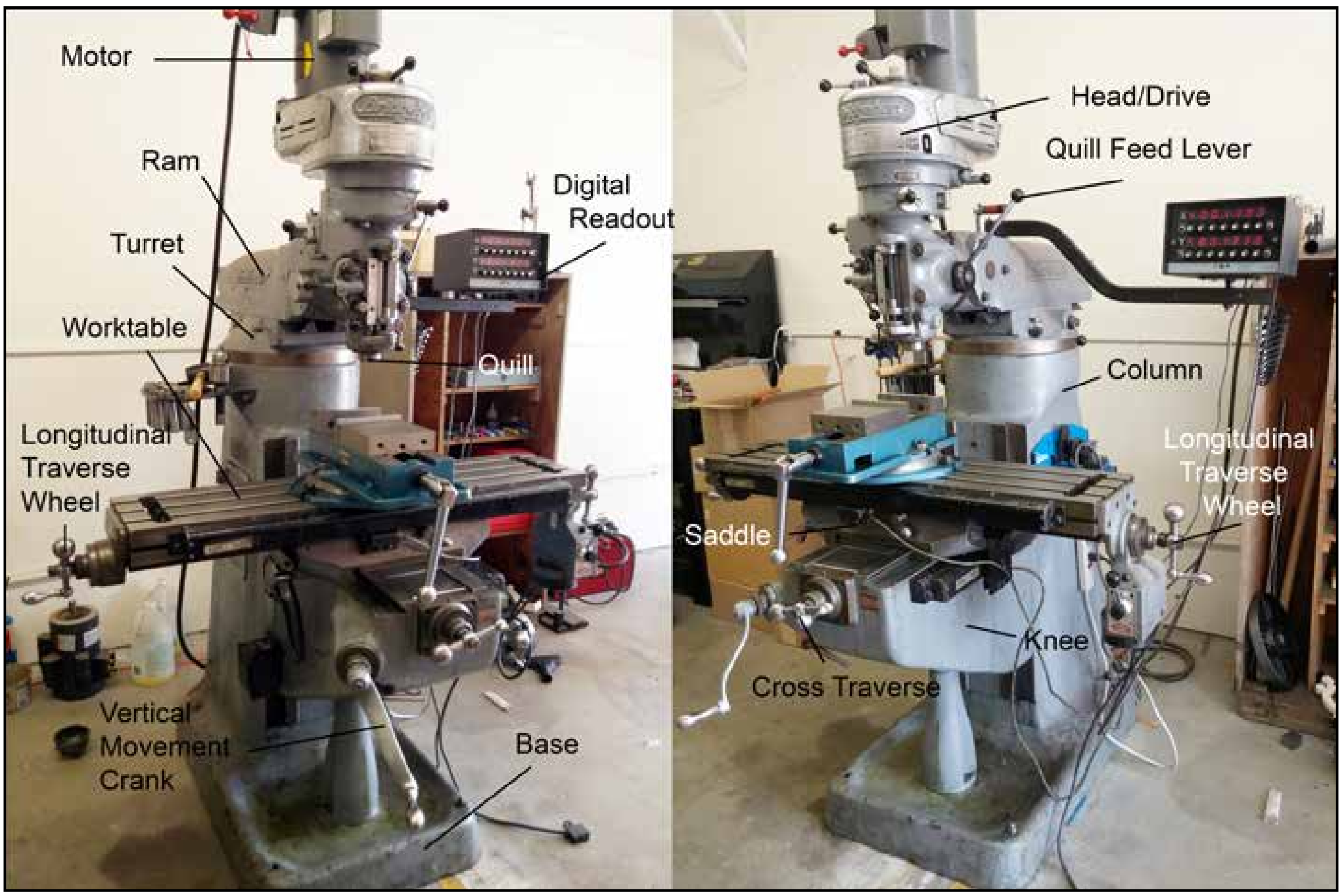

***Figure 20**: Parts of the mill.*

[5] *Although the machine may be equipped to thread, for beginners it is still recommended to perform threading operations by hand.*

be made with the machine off to prevent damage. The spindle may also need to be slightly spun by hand to allow the gears to mate properly.

The head of the mill may also tilt both side to side (yaw) and fore and aft (pitch/nod). This further enhances the versatility of the vertical mill. Tilting the head will allow you to use tooling designed for 90° cuts to cut at various angles. Adjustment of both the yaw and pitch is controlled by locking and adjustment bolts on the head and ram. Curved graduation bands on the head and ram give a close approximation of the head's alignment.

- **Worktable**. The worktable moves longitudinally (side to side) on ways on the saddle. The worktable is precision ground and features "T" slots on its surface to mount clamps or other vises. A lead screw under the table engages a nut on the saddle. When the longitudinal traverse wheel is turned, the table moves side to side atop the saddle.
- **Quill**. The quill moves up and down and facilitates the Z feed of the spindle/tooling. The quill feed lever and wheel control the vertical movement of the quill. A linear graduation band on the head will show the approximate travel of the head.
- **Spindle**. The spindle translates horsepower and torque from the motor/head into the tooling. There are various ways for the spindle to hold the tooling from collets to sleeves or arbors and chucks, but whichever method is used, the attachment always fits into a tapered cavity in the spindle. The collet is the most widely used method. The accuracy of the spindle's construction and its rigidity as well as the quality of the bearing system of the spindle is key to the machine's long-term performance and precision. The bearings must be able to hold up to the abuse of the power and load forced upon them.

  The typical manual mill will use a drawbar-type system to hold the collet and tooling. The drawbar grabs onto the back of the collet and draws it up into the tapered cavity of the spindle, tightening the tapered collet around the tolling. The drawbar may be manual or automatic. Because there are different taper types in the spindle, you will have to match your collets and sleeves appropriately. The R8 taper (developed by Bridgeport®) is currently one of the most widely used taper types for use with R8 collets and other accessories. The draw bar protrudes out of the top of the head and allows you to use a wrench to secure or release the tooling.

  A switch or lever on the head controls the direction of the spindle's rotation: clockwise (CW) or counterclockwise (CCW). This allows you to use both right- and left-hand cutters. This allows for greater versatility when considering holding, feed direction, and climb versus conventional milling.
- **Quill Feed Lever and Wheel**. The quill feed lever and wheel control the vertical movement of the quill and spindle. The quill feed lever will give you gross adjustment while the fine adjustment wheel will give you more precise control. Some machines may also be equipped with an automatic quill feed that can be set to move at different rates. This function would be controlled by the quill feed rate selector.
- **Longitudinal and Cross Traverse Wheels**. The longitudinal and cross traverse wheels control the table and saddle's side-to-side and fore and aft movement respectively. The longitudinal traverse wheel is located on both sides of

the table while the cross traverse wheel is only on the front of the machine. The mill may also feature automatic feed control (coupled with manual) to allow the operator to set the table to move automatically for long, straight cuts, slots, or facing.

Micrometer dials near the longitudinal and cross wheels give a very close approximation of the distance the table wheel moves based on revolutions of the wheels. One complete revolution of the wheel may move the table between .1 and .05 in., which is completely dependent on the thread pitch/tpi (threads per inch) of the table and saddle's lead screw. A lead screw with a pitch of 10 tpi would move the table .1 in. every 360° of revolution of the wheel, while 20 tpi would move it .05 in. It was stated that the micrometer dial is a close approximation to the distance it shows the wheel moves the table because backlash in the lead screws may throw the dial off by as much as .0015 in.

- **Ram/Overarm**. The ram slides on the turret on a large dovetail and allows the head to be repositioned over the table. It allows the head to move along the Y-axis to provide greater diversity of the machine as well as clearance for larger parts. Although the ram is adjustable for position, it is fixed while the machine is running by the ram locks. The ram can be adjusted using the locking (on top of the turret) and adjustment (on the side of the turret) bolts.
- **Swivel/Turret**. The turret sits on the column and allows the head to rotate over the table. It rotates centered on the column and moves the ram/head in an arch across the table, further lending to the mill's capabilities. Like the ram, the turret is also fixed while the machine is running. The turret is adjusted by loosening the locking bolts on top of the turret (on both sides of the ram) and rotating the turret by hand. A curved graduation bands on the column will show the approximate travel of the turret.
- **Knee**. The knee supports the saddle and table and moves up and down. The knee rides on ways that run parallel to/on the column. The vertical movement crank is used to move the saddle up and down. It can also be locked in place to hold its position. The top of the knee is precision machined to ensure it is square and true to the saddle and tabletop. The knee may also feature power feed.
- **Vertical Movement Crank**. The vertical movement crank controls the up and down movement of the knee. Moving the table up and down provides even greater versatility of the mill by allowing various sizes of workpieces.
- **Saddle**. The saddle sits on the knee and moves horizontally (fore and aft) and supports the table. It moves on ways on the knee and is controlled by the cross traverse wheel. The top of the saddle features ways that the table moves on. The saddle must be precision machined to ensure it is square and true to the table and knee.
- **Column**. The column sits on the base and supports the turret. It is a very heavy casting that features precision ways that run parallel with the column and guide the knee up and down. The column may also have provisions for an oil pump and reservoir for the spindle.
- **Base**. The base is the foundation of the mill. It supports both the column, which supports the turret, ram, and head, and the knee, which supports the saddle and table. The base may have provisions for a coolant reservoir. The weight of the base

and column will steady the machine so it does not need to be mounted to the floor, but will still need to be leveled.

- **Digital Readout (DRO)**. Some machines may be equipped with a digital readout. It uses sensors attached to the machine to display travel of one (X or Y), two (XY), or three (XYZ) axes. The DRO will allow you to set zero or start points on the workpiece once the edge has been found. The DRO is a nice supplement to the micrometer dials located on the longitudinal and cross traverse wheels.

OPERATIONS

The versatility of the mill and its tooling, vises, and accessories make it extremely well-suited for many different operations. The tooling used is completely dependent on the type of milling being performed. One workpiece may have several operations performed on it by simply swapping tooling and the way the part is being held.

Below is a list of the most common types of operations performed on a vertical-style mill.

- **Facing**. Facing is the process of cutting a flat face on the workpiece. It is accomplished with the use of face mills, fly cutters, and even end mills. Facing is typically a first step in a series of milling operations, creating a flat, square face on the workpiece to base all remaining work against (measuring, marking, locating, clamping, securing, or jigging). The face mill or fly cutter cuts very shallowly and because the cutting surface is on the outside of the tool, cuts must come from the outside of the workpiece horizontally. Most facing operations use a cutter that is wider than the workpiece for the greatest precision of the face, although a smaller tool (end mill) can be used. Facing with an end mill is more time-consuming and does not produce as smooth of a finish as a facing mill or fly cutter.

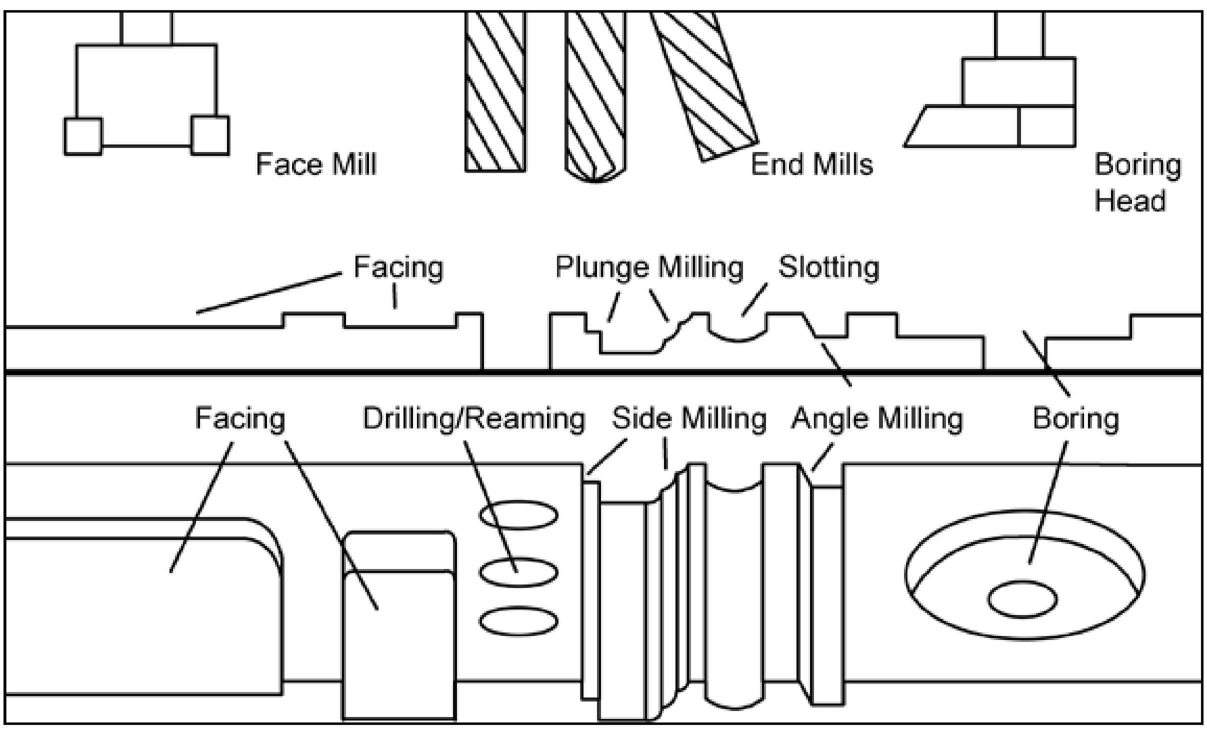

Figure 21: Milling operations.

- **Drilling/Reaming/Boring**. Drilling on a mill is very similar to drilling on a drill press. With the use of a drill chuck adapter you can even use standard twist drill bits. The same types of drilling are also possible: through, stop, and spot. You can also use some end mills to drill a hole. Depending on the type of tooling/bit used, the bottom of the hole may be flat (end mill or reamer) or conical (twist or spot drill). Spot drilling creates a conical dimple on the surface of the material used to center and start a twist drill in a precise location and prevents walking. A technique known as peck drilling (continuously raising the tooling to remove chips) is employed for some materials while drilling with a mill.

  Reaming is the process of enlarging and refining an existing hole with a precision bit. Reaming requires a preexisting hole or a hole to be drilled that is .010 in. – .015 in. smaller than the desired finished hole. Reaming will leave a clean, concentric hole with a flat bottom and can also cut precision tapered holes.

  Boring is the process of enlarging a preexisting hole with larger tooling (boring head) or by using an undersized end mill to cut a larger hole. Boring is also used to achieve greater precision in the final diameter of the hole or to cut tapered holes. It also ensures holes are straight through their entire length and is typically used to make larger holes than drilling or reaming.

- **Plunge**. Plunge milling is the process of cutting down into the workpiece using the bottom of the tooling to perform the cutting. The difference between plunging and drilling or boring is that once the tooling has reached a specific depth, it is backed out and relocated for another plunge, enlarging the hole or cutting a step or specific profile. Plunge milling is not restricted to holes or other voids; it can also be used to rough or shape the outside profile of the workpiece. Plunge milling is also an alternative to side milling when tooling or ease of access is not available.

- **End**. End milling is the process of cutting a flat surface that may be vertical, horizontal, or at an angle in reference to the table's surface. It may be performed in any direction (XYZ) and can simultaneously cut along its side and bottom faces. End milling gets its name from the use of its tooling: the end mill. End milling may also be known as peripheral milling.

  End milling can be used to cut pockets, slots, grooves, or ramps. These types of cuts require the tooling to cut two to three separate faces (one to two sides and bottom) at once. Slots are typically three-sided (two sides and bottom, all right angles) and extend through the entire length of the workpiece. Slots that are closed at both ends are pockets. Grooves are similar to slots but feature more of a "T" or "t" shaped cross-section. Ramps are similar to slots, but instead of a flat bottom they feature a slanted bottom. The bottom face of the end mill may also be spherical. These are known as ball mills. The ball mill will cut almost the same profile as the end mill with the only difference being the bottom of slots are round with a "U" shaped cross-section.

- **Angular**. Angular milling is the process of cutting a surface that is neither parallel nor perpendicular to the cutter's axis. This means if the cutter is vertical and the workpiece is horizontal, the cutting surfaces may be at any angle in between. In gunsmithing, the most popular angle

milling operation is cutting dovetails for sights or trunnions. Because of the delicate nature of most dovetail cutters, the majority of the cut is made by an end mill and is followed by the dovetail. The two most popular angles for cutting dovetails for sights are 60° and 65°. Angular milling can also be accomplished with square tooling by angling the head.

- **Radius**. Radius milling is the process of milling a radiused profile on the workpiece. Radius milling requires a special fixture called a rotary table. Rotary tables may be mounted horizontally or vertically and rotate around an XY- or Z-axis. The rotary table allows you to clamp the workpiece in line with its rotational axis and rotate the piece against the tooling. Radius milling may also be accomplished with radius mills or corner-rounding end mills. Radius mills feature a cross-section with a concave radius so they can cut a convex profile.

CONVENTIONAL VS. CLIMB MILLING

Conventional and climb milling refer to the direction of the cutting tool's rotation versus the travel of the workpiece when cutting the sides/walls of a workpiece with an end mill or similar tooling. In conventional milling, the workpiece is fed against the rotation of the cutter and the material is almost "scooped" away. Conventional milling produces lower cutting forces and is preferred for roughing or heavy cuts and is regarded as standard practice. It produces a chip that starts at zero thickness and increases. Conventional milling is also preferred when a machine has excessive backlash or with castings, forgings, or parts that have been case-hardened because cuts start under the workpiece's surface and any backlash is taken up by the force of the cut.

Conventional milling has some drawbacks. It may cause more heat to diffuse through the workpiece and can lead to work hardening. The cutter also wears faster and pushes the chips in front of the cutter, which could lead to a rough

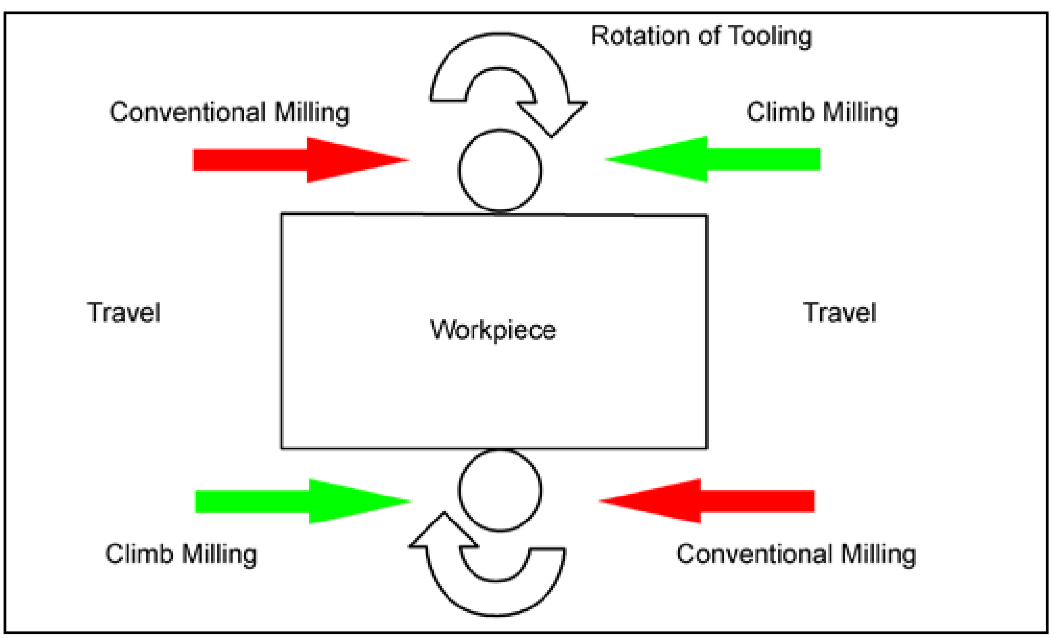

Figure 22: Conventional or climb milling.

finish. The cutting force may also "scoop" too much material and cause the workpiece to be out of spec. Conventional milling produces an upward force that may cause the part to move and also requires more torque to perform the same cut.

Climb milling occurs when the workpiece is fed in the same direction as the cutter's travel, appearing as it is "climbing" the material. It produces a chip that starts at its maximum thickness and decreases. Heat generated from cutting is transferred to the chip, keeping the workpiece cooler. Climb milling should be reserved for shallow, finish cuts (.001 in. – .002 in.) as it leaves a better surface finish. Because climb milling is preferred for shallow cuts, tooling experiences less wear and lasts longer and is also the preferred method for high performance carbide cutters. Climb milling also requires less torque to perform the same cut.

Climb milling also has some drawbacks. Because climb milling pulls the workpiece through its travel, any backlash in the machine will create inconsistent cuts. Also, if deeper cuts are attempted while climb milling, there is a higher chance that you will break the tooling.

SETUP

Thoughtful planning before setting up your mill will save you many headaches down the road. Your first consideration is the location. You want to place your mill in an area that will allow you to access the whole table and allow you to work on longer pieces without bumping into things. You also want to consider your power source. Is your location close enough to an outlet or will you need an extension cord?[6] Once you have your location, you will need to true the mill.

Start by leveling the base. Most workshop floors tend to be fairly level, so this is usually as simple as setting the mill in place. If the floor is not level, you will need to shim the base. Make sure you level the base on both the X (side to side) and the Y (fore and aft) axis to ensure the column is square, plumb and level. Next, you will need to square the head and table/vise.

TRAMMING THE HEAD

Squaring or truing the head of the mill to the table is also known as tramming. If the head is not square to the table, it is impossible to mill square features into the workpiece and it will leave a saw-tooth-like pattern on the workpiece's surface (from the shallow, angled passes). Because the head of the vertical milling machine can tilt from side to side (yaw) and fore and aft (pitch/nod), there is the possibility that over time and use the head can drift. The markings on the curved graduation bands near the rotation points on the head and ram are only for close approximation and should not be entirely trusted. You should check and adjust the head so the spindle will be true or normal to the plane of the table; this should be done either a few times a week, or when machining a part that requires great precision, or when the head has been greatly tilted, or after performing deep, heavy cuts. You may also tram the head to a table-mounted vise that has been squared to the table.

Tramming the head is easily accomplished with the proper tools but is extremely frustrating without. The best tool for the job is a spindle-mounted tramming bar with a dial indicator at each end, but can also be done with a dial indicator that is mounted to the spindle or quill.[7] You

[6] *Be aware you may also have to ground the motor to prevent damage or electric shock. Please refer to your owner's manual for instructions for your particular model.*

[7] *A quick, coarse method of tramming the head is accomplished using a precision metal square or cylinder square. Lower the quill/spindle and raise the knee until the spindle is about 1 in. – 2 in. away from the table. Align the square against the table and quill along both the X- and Y-axis. Adjust the head accordingly. This method, if done with care, can get the head within .002 in. – 0 .003 in., which may be acceptable for some jobs.*

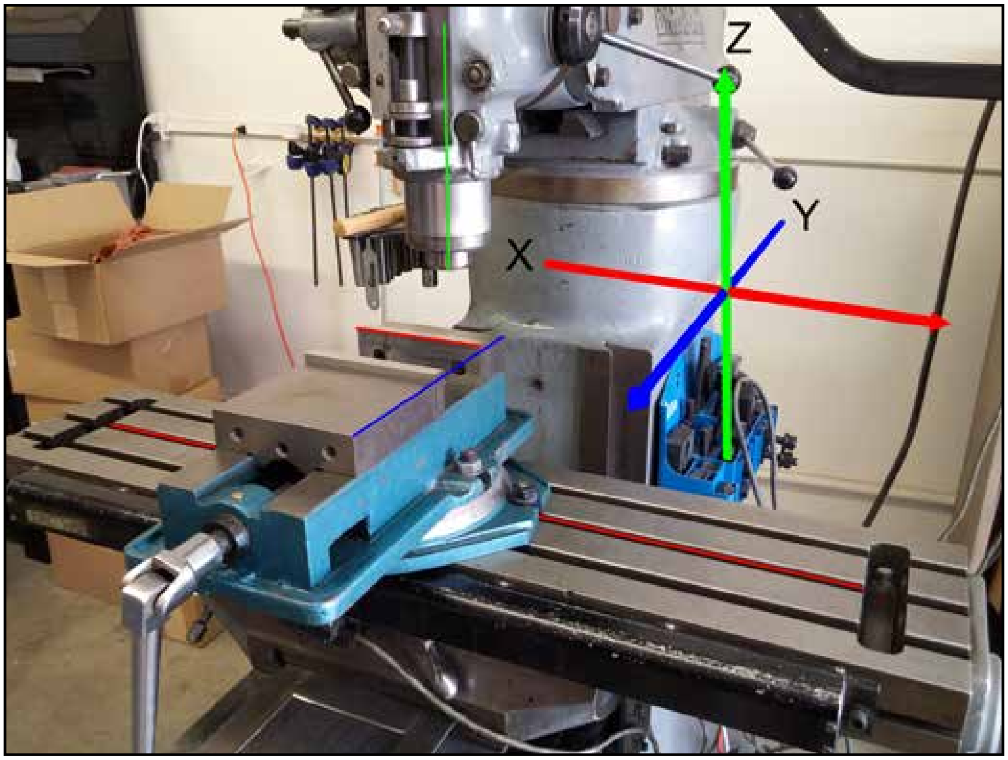

Figure 23: Tramming the head. & *Figure 24: Squaring the vise.*

may also want to use some type of riser (such as precision machined parallels), but they are not necessary. The head will need to be trammed along both the X (yaw) and Y (pitch/nod) axis.

Let's start with the X-axis and address any yaw in the head. Mount the tramming bar in the spindle or the dial indicator to the spindle or quill. Make certain you clean the tramming bar/ dial indicator's surface as well as the spindle/ quill and the table/vise. Any chips, dirt, or debris may give a false reading. If you are using risers, place them on the table parallel to the Y-axis, spaced evenly apart and the same width as the dial indicator's reach. If you are using a dial indicator, rotate the spindle until it is on the left side of the table. Position the indicator so it is sitting about 45° to the table's surface.

Lower the quill or raise the knee until the indicator touches the riser/table/vise and it is preloaded between .005 in. and .010 in. Zero the indicator by turning the dial on the housing. Rotate the spindle 180° to the right side of the table. Watch the direction of the dial. If it moves clockwise (CW), then the right side of the table is higher. If the dial moves counterclockwise (CCW), the left side of the table is higher. Also note the amount of dial travel. If the dial moves .006 in. from one end to the other, you will only need to adjust the head .003 in. in the correct direction. If the left side of the table is high, you need to move the spindle to the right and vice versa. Adjust the head by loosening the locking bolts on the front of the head and turning the adjustment bolt, then measure again. In a perfect world, the dials would not move as they rotate 360° around the table. In the real world, .001 in. – .0015 in. are perfectly acceptable for most applications. Tighten the locking bolts and measure once more to ensure proper tramming.

Now it is time to tram the Y-axis. This is the same procedure as the X-axis, only this time the head is moving fore and aft (pitch/nod). The tramming bar/dial indicator should still be mounted. You will have to move the risers (if applicable) parallel to the table and space them out evenly between the diameter of the bar/dial's travel. Turn the spindle until the indicator is facing you.

Lower the quill or raise the knee until the dial indicator is preloaded .005 in. – .010 in. Set the dial to zero and rotate the spindle 180° to the rear of the table. If it moves clockwise (CW), then the rear of the table is higher. If the dial moves counterclockwise (CCW), the front of the table is higher. Also note the amount of dial travel. If the dial moves .006 in. fore and aft, you will only need to adjust the head .003 in. in the correct direction. If the front of the table is high, you need to move the spindle back and vice versa. Adjust the head by loosening the locking bolts on the sides of the head and turning the adjustment bolt on the ram; then measure again. Tighten the locking bolts and measure once more to ensure proper tramming. Your head is now properly trammed.

SQUARING THE VISE

Often, you will use a table-mounted vise to hold parts that you are milling. You have just finished tramming the head, so your table should already be true and level. Squaring the vise ensures the vise jaws (top and faces) run parallel with the table and its travels (Figure 24). This enssures that the part being secured is square to the direction on the table's travel and any cuts made will be true.

Like most things manufactured for use with a mill, the vise is a precision accessory. The base of the vise and the floor of the vise jaws and the vise jaws themselves are all machined square and true. When the vise is square and true to the table, it makes leveling and indexing the workpiece much easier. Placing a square workpiece flat and flush against the channel's floor or square to the top of the jaws will ensure any cuts to the top of the workpiece will be square.

The only thing needed to square a vise is a dial indicator. The indicator is mounted on a rod that is in turn mounted in a collet in the spindle. Clean both the table and the bottom of the vise of any dirt, debris, or chips (or anything else that may cause the vise to be mounted crooked or uneven). Set the mill into low gear to prevent the spindle from easily spinning. Loosely mount the vise to the table. You want the vise snug enough that it does not move freely or easily, but you also want it to be loose enough that you can make adjustments. You will want to square the top of the vise jaws.

Align the probe of the indicator with the top of the vise jaws on the left side of the vise. Lower the quill or raise the knee until the probe barely touches the jaw (.005 in. – .010 in.). Zero the indicator. Use the longitudinal traverse wheel to move the table to the left until the indicator is sitting on the right side of the vise. Note the amount of indicator movement and the direction of the indicator's travel. Clockwise means the right side of the vise is higher. Counterclockwise means the left side is higher. You will need to adjust the vise or shim it. If the left side is high, you will need to shim the right and vice versa. If the vise is .004 in. out of level, start by shimming it .002 in. Adjust the vise until you are between .0005 in. and .001 in.

Next you can true the vise jaw's face. Open the jaws until you can get the dial probe between the jaws at a 45° angle. Align the table until the indicator is almost touching the left face of the rear vise jaw. Use the cross traverse wheel to preload the indicator .005 in. – .010 in. against the face of the rear jaw. Zero the indicator. Use the longitudinal traverse wheel to move the table left until the indicator is touching the right side

of the jaw's face. Note the amount of indicator movement and the direction of the indicator's travel. Clockwise means the right side of the vise is closer. Counterclockwise means the left side is closer. You will need to adjust the vise accordingly. If the right side is too close, you will need to tap it away and vice versa. Tighten the vise down and recheck your alignment. Your vise is now level.

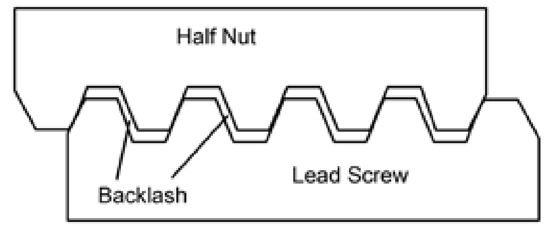

Figure 25: Measuring backlash.

MEASURING BACKLASH

Backlash is an unavoidable aspect of the lead screw design. It is the amount or play or "free space" between the threads of the lead screw and the nut. When the table is moved one way or the other, the threads of the screw must first engage the threads of the nut; this is known as preloading. When the feed direction is changed, the backlash must be taken up before the table will move again. Backlash will affect the readings on the micrometer dials of the longitudinal and cross traverse wheels.

Knowing how much backlash your machine has will save you a ton of headaches down the road. The last thing you want to do is machine a precision part that is .010 in. out of spec because you did not account for the machine's backlash. Measuring backlash is fairly simple. All you need is a dial indicator mounted to the table. You will need to measure both the X- and Y-axis.

Lower the quill or raise the knee until the spindle is about an inch off the table. We will measure the backlash in the X travel first. Move the table to the left to remove any preload. Position the indicator on the left side of the table so that the indicator is barely touching the spindle. Zero the indicator. Zero or note the location of the micrometer dial of the longitudinal traverse wheel, if possible (some machines may not be equipped).

Begin turning the longitudinal traverse wheel to move the table to the right while watching the dial indicator for any movement. Once you have noticed even the smallest movement of the table (<.0001 in.), stop turning the wheel. Note the amount of travel of the micrometer dial versus actual travel. If the dial says you have moved .007 in. and the indicator says .001 in., then subtract the actual movement from the perceived movement and you will get your backlash (.007 in. – .001 in. = .006 in. of backlash). This means that if the table is not preloaded, your micrometer dials will give a .006 in. false reading.

Use the same process for the Y-axis as well. You may find that the X- and Y-axis have different amounts of backlash. Over time, wear on the lead screws and nuts will increase the amount of backlash the machine has. Understanding and knowing your machine's specific X and Y backlash will allow you to compensate for it every time you use the mill.

CONTINUED SETUP

Before start up, make certain the mill has been properly lubricated. Refer to your owner's manual for specific lube points. Your mill may be equipped with an oil pump and reservoir that is operated manually or automatically and may simultaneously oil the saddle and table ways and the quill/spindle. If the machine is not equipped with a pump, the mill will have some type of oil fittings near the ways and on the head. These fittings are designed for use with either oil or

grease. Refer to your owner's manual for specific directions on proper lubrication. Failing to use the proper lube (oil instead of grease or vice versa) will lead to damage to the machine.

You may also consider wiping the table, saddle, knee, column and any other unfinished metal with a light coat of oil to prevent rust. You will also want to wipe the ways of any chips or dirt and debris. If the machine is equipped with way wipes, remove and clean them. Over time the machine's parts will wear against each other and you will need to adjust the gibs and measure runout. This is discussed later in the section under "Maintenance." For now, the machine is set up and ready for use.

MILLING

Now it's time to perform a milling operation. For the purpose of this section, we will be discussing milling a dovetail for dovetail sights on a pistol slide with a dovetail cutter. It seems like a simple task, but when performed correctly, the slot is the result of many carefully considered variables. Where is the dovetail going to be? What material are you cutting? You should develop a mental or physical checklist of the steps involved in any milling processes.

- **Location and Layout.** Planning out the location of your dovetail is one of the most important steps. Often, you only get one chance to cut a dovetail in the correct location, so there is no room for error or you may find yourself buying a replacement slide or barrel. You will need a handful of tools and materials.

Various calipers, rules, squares, combination squares, protractors, and levels, along with scribes, and layout dye are all used to help locate the dovetail. The workpiece (slide or barrel) is first covered in a thin coat of layout dye that is allowed to dry for several minutes. Using drawings or plans and known measurement of your workpiece, you can start to layout your dovetail location.

Use rules, squares, and protractors and scribes to "draw" the layout on the surface of the workpiece. Use the straight edge of the rules and squares to scribe your lines. Use known square or true edges to measure against. Measure several times to ensure you are marking the workpiece with the correct dimensions.

The dovetail sight varies greatly in its dimensions and is not standardized in the industry. Even front and rear dovetails may not be the same dimension. The width, depth, and angle of the cut may be different, as well as the cut's location front and back. You should have the sights on hand to use to dimension the slide. Sights are typically between .150 in. and .350 in. wide, .070 in. and .090 in. deep, with 60°– 65°shoulders. Also be aware that you will want to undersize the dovetail .002 in. – .003 in. so that the sights can be force fit (swaged).

For the purpose of this exercise, let's say the dovetail we are cutting is .330 in. wide and .075 in. deep, with a 65° shoulder. You do not want the cut to be made in one pass, so a roughing cut must be made even though your cutter may be

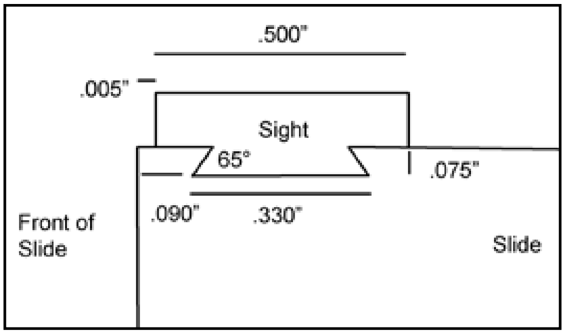

Figure 26: Layout of a dovetail cut.

the exact dimension of the cut (.330 x .075 x 65°). Once the roughing pass has been made, you can cut the rest of the dovetail in one pass. You will also have to layout the initial roughing cut, but first you will have to calculate the width of the cut. We already have the width (C), depth (B), and angle (A) of the cut, so we can use the following formula to find the width of the roughing cut (E) by subtracting (D) twice.

The formula is as follows:

C - [2 x B / Tangent[8] (A)] = E

.330 - [2 x .075 / Tangent (65)] = E

.330 - (2 x .075 / 2.1) = E

.330 - (2 x .035) = E

.330 - .070 = .260”

This means that E or the width of the roughing cut is .260 in. or .010 in. bigger than ¼ in. Now you will need to locate the center of the cut along the length of the slide (fore and aft). Typically, the front face (muzzle end) of the slide is at a right angle (square) to the top of the slide, making locating the cut easily measured from the front. You want to measure the width of the sight (not the base) so that you can ensure the sight is not hanging off the front of the slide. Let’s say the sight is .5 in. wide and we know we want it close to the muzzle to extend the sight radius, but not so far forward that it compromises the dovetail’s integrity. We will set the sight .005 in. back from the front of the slide. This means the center of the cut will be .255 in. back from the front of the slide [½ the width of the sight (.250 in.) + .005 in.], leaving .090 in. material in front of the longest point of the dovetail.

- **Material**. Knowing your material is also a big part of milling a dovetail properly. Nine out of ten times you can use any HSS dovetail cutter to slot your workpiece. On the tenth time, however, you may have to cut a hardened steel workpiece and your average high speed steel (HSS) cutter may not be enough. Modern dovetail cutters have been specially developed for the material they are intended to be used on and in the case of a hardened part, carbide would be best suited.

Knowing your material will allow you to choose the tooling that will work best for the job at hand. Once you have selected the tooling that will work best, you can set the speed of your spindle. Most machines feature some means of speed adjustment in both a low and high range. A good rule of thumb is you want the bit to be harder than the workpiece and to move as fast as necessary to provide a smooth, clean cut. Small or shallow cuts and soft materials usually require high

[8] *The figure for the tangent can be found using a scientific calculator or an online tangent calculator. The tangent for 60° is 1.732 and 65° is 2.144.*

rpm, while large diameter or deep cuts or hard materials use lower rpm. Cutting too slow or too fast will put excessive strain on the tooling and workpiece and will leave a sloppy, burred, or chipped finish.

It would be smart to have a machinists' handbook on hand in case there is ever a question of what type of tooling to use at a given speed for a specific type of material. These handbooks can be very valuable to any machine shop, as they contain figures for cutting speeds and feeds for various materials and types of tooling as well as other info valuable to machinists, engineers, draftsmen, and toolmakers.

Assuming our slide is hardened high carbon and we are using carbide tooling, we will need to set the speed for both the ¼ in. end mill and the .330 in. dovetail cutter. Spindle speed for the ¼ in. carbide end mill should be around 1,500 rpm while the cutter should be much slower, below 700 rpm (based on manufacturer recommendations). At these speeds, the cutters are fed through the part fairly slowly.

- **Securing and Truing**. You want to secure your tooling and workpiece and true and square the workpiece while cutting to ensure the most precise, cleanest dovetail possible. Any movement of the tooling or workpiece while cutting will cause the dovetail to become out of spec or irregular, or could potentially fling the workpiece across the room, which could be extremely dangerous.

  Securing the tooling is fairly simple. Make certain the tooling is centered in the collet, just above the flutes but before the flat that may be present on the shank. Ensure that the tooling, collet, and spindle are clean and clear of debris and chips. You may want to place a shop towel or rag below the spindle just in case you drop the collet/tooling. If the hard carbide cutter hits the table or vise, it will surely break. Insert the tooling/collet into the spindle and hold it in place with one hand while tightening the drawbar from the top of the machine with the other. Once the collet is secure, you can let go of the tooling and use a wrench to tighten the drawbar.[9] Be sure to tighten the drawbar without putting too much torque on the wrench. Over- or under-tightening the drawbar can lead to damage to the tooling, collet, spindle, or workpiece. Make sure you remove the wrench when you are done!

  Usually a precision machine vise is all that is needed to secure the workpiece while cutting. Some of these table-mounted vises may even rotate or use two pieces to secure centers, adding another degree of adjustment and further easing setup. You want to clamp the workpiece hard enough to prevent it from moving while cutting, but not so hard that you mar the finish or crush the piece. You also want to ensure the part is centered in the vise jaws to make certain it is being clamped evenly. You may need some type of support inside of hollow workpieces to prevent them from being crushed while clamping. You may also need some type of jig to hold some workpieces in a specific manner.

  Most slides feature flat sides that make positioning and alignment easier.[10] Whatever you are cutting, you will want to use a layer of masking tape on the areas being clamped to prevent marring the finish. You may also have to use a set of parallels as risers and supports to

[9] *You will need to put the machine into low gear (around 200 rpm) or set the brake while tightening the drawbar.*

[10] *For the purpose of this exercise, we are mounting the slide longitudinally (parallel to the X-axis travel).*

bring the top of the slide above the vise jaws and prevent it from moving down, away from the cutter. You will initially snug the workpiece so you can make any adjustments before clamping down.

Leveling the workpiece can be as simple as ensuring it sits flush against the parallels or as tedious as making adjustments multiple times. Checking the position of the workpiece can be done in the same manner as squaring the vise (refer to section "Squaring the Vise"), with a dial indicator. You will need to level the workpiece along the X- and Y-axis. Taking the time to verify the workpiece is true will guarantee the sight is mounted correctly.

- **Lubrication/Coolant**. Some materials and processes may require some type of lubrication or coolant. The lube or coolant serves two purposes. First it keeps the tooling cool, which prolongs tool life and cutting surfaces. Second, it aids in clearing chips from the cut. Every machinist has a lube or coolant he or she swears by. Cutting fluid is most commonly used, but motor oil, mineral oil, vegetable oil, kerosene, lard oil, or even dish soap may be used as substitutions.

  Aluminum, brass, bronze, and copper (nonferrous) will typically use the same type of lubricants (soluble oil, kerosene, or lard oil), while ferrous metals (iron and various steels) will use soluble oil, sulfurized oil, lard oil, or mineral oil. The type of oil used for specific materials may also change with the operation being performed. You may also find that blends of different oils and coolants may work better for certain applications.

  There is another school of thought that using oil for cutting is counterintuitive. Because oil is used to make two surfaces slide against each other, it is believed the tooling will not cut as effectively as it would without lube. You may have to test certain combinations of materials, tooling, and lubes to find what works best for you. Regardless what you use, sharp tooling will always give you the best results.

- **Edge Finding**. Edge finding is one of the most important steps in any milling project. Edge finding helps you properly locate the position of the workpiece and zero your starting points for your cuts. Most edge finding is done with a tool known as an edge finder, which precisely locates the edge of the workpiece, but a more coarse method can be accomplished with feeler gauges. An edge finder may be mechanical (spring-loaded) or electronic (the machine, edge finder, and workpiece complete a circuit) and will vary in its degree of precision. A mechanical edge finder is used while the spindle is spinning, whereas the electronic edge finder is used stationary.

  For the purpose of this exercise, we will use a combination of the mechanical edge finder and the feeler gauge method. Mount the body of the edge finder in a collet and the collet in the spindle. Set

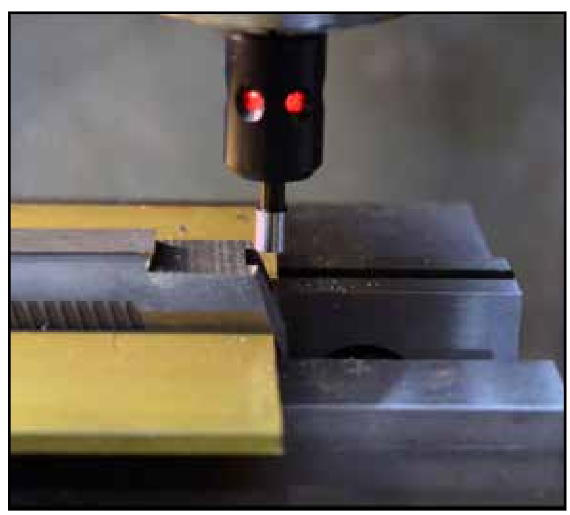

Figure 27: Locating the edge of a workpiece.

the spindle to 1,000 rpm. First, we will locate the center of the dovetail using the muzzle as our starting point. Move the table until the muzzle end of the slide touches the edge finder and it begins to spin true (this is centered). Move the table a small amount (X direction) until the edge finder kicks the tip off to the side (this is offset and is about .0005 in.). This is not the edge of the workpiece.

Remember, you are aligning the edge of the workpiece and the edge of the tip of the edge finder. If your tip is .200 in., this means you are .100 in. away from the edge. Raise the quill or drop the knee until the edge finder clears the top of the slide. Move the table .100 in. over the slide. This places the center of your tooling/spindle directly over the edge of the muzzle end of the slide. Now you can note the zero (starting point), or zero your longitudinal traverse wheel micrometer dial (if applicable), or you can zero the X-axis if your machine uses digital readout (DRO).[11]

Now that you have your edge, find the center of the dovetail. Using our calculations from earlier (.500 in. wide sight, back .005 in. from the front of the slide or .255 in. [½ the length of the slide + .005 in.] from the front of the slide). Move the longitudinal traverse wheel until the DRO or micrometer dial shows .255 in. over the top of the slide. This is the center of the dovetail cut.

Now you can set the depth (Z-axis) of the cut. Replace the edge finder with a ¼ end mill. This is where the feeler gauge comes into play. You can use any thickness of feeler gauge you choose, but remember, you will need to add or subtract the thickness of the gauge. For the purpose of this exercise, we will be using a .005 in. feeler gauge.

Lower the quill or raise the knee and use the cross traverse wheel to move the slide under the end mill. Place the feeler gauge atop the slide and lower the quill until the end mill touches the gauge. Remove

***Figure 28**: Cutting a dovetail.*

[11] *You may also want to use a dial indicator once your zeros have been set if you do not have a DRO or if you do not trust your dial micrometers.*

the feeler gauge and move the table until the end mill clears the slide. Lower the end mill .080 in. (.005 in. for the feeler gauge and .075 in. for the depth of the sight). You are now set up for location and depth of the cut. Now you will only need to manipulate the cross traverse wheel (Y-axis) to perform both passes (the initial rough with the end mill and the final pass with the dovetail cutter).

Safety. You are almost ready to cut the dovetail, but first you need to do a last minute safety check. Make certain both your tooling and part are secure and the work area is clear of anything that may touch the tooling or spindle while spinning.[12] Also make sure the feed wheels are free from obstructions and that the drawbar wrench was removed. Be sure to check yourself for clothes, jewelry, gloves, or hair that may become caught in the machine. This is your last chance to prevent damage or injury, so be certain you go over your safety checklist. This may seem like you are being overly cautious, but it only takes a small lapse in judgment or procedure to lead to disaster.

- **Cutting**. It's finally time to cut the dovetail. By now you are realizing that the actual act of cutting a dovetail is only about 10% of the process, while preparation is 90%. Turn the machine on. Use the cross traverse wheel to feed the slide into the cutter very slowly. Feed the slide until the cutter slots the slide all the way across. Let the cutter work without being forced. If you are moving too fast, the end mill will chatter and squeal and will begin to burn off oil. If you are moving the correct speed, the cutter will not chatter and make noise and the oil will not burn off.

***Figure 29**: The sight installed in the slide.*

Once you have made the initial roughing pass, remove the end mill and insert the dovetail cutter. Index the cutter by setting the point of one of the teeth flush to the bottom of the groove. Make sure to tighten the cutter and move the cutter away from the slide. Turn the machine on and use the cross traverse wheel to feed the slide into the cutter very slowly. Feed the slide until the cutter slots the slide all the way across. You now have a dovetail that has been cut to spec to fit your sight.

There may be some minor fitting to get the sight to fit in the dovetail. You can use a 65° triangle file with a safe edge to open the dovetail up enough for the sight to start in the slot. You will only want to take two to three swipes with the file before checking the sight's fitment. You should be able to push the sight into the dovetail by hand about one-third to one-half of the way in. Use a brass punch and a small hammer to drive the sight the rest of the way in. You now have a new sight mounted on your slide.

[12] *Make certain to turn the machine off anytime you are changing tooling.*

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Tooling, Vises, Fixtures, and Accessories

There are many tools and accessories that you can use to perform various operations that further increase the versatility of the mill. Knowing what accessories are available will allow you to select the best tools for the job at hand.

TOOLING

There is a huge array of tooling of different sizes and profiles, made from different materials for different materials, that all serve to complete one specific purpose: cutting. Using the correct bit for your job will ensure the smoothest operation.

- **Face Mill/Fly Mill/Shell Cutter**. Face mills and fly cutters are designed to "face" or true the surface of a workpiece by making light, shallow cuts. Shell cutters also perform facing operations but are used more for roughing or removing a lot of material at once and are similar in design to face mills. The face mill must be attached to a holder, which consists of an arbor, drive keys, and a retaining bolt. Carbide cutters (4 – 6+) are secured to the cutter with screws and are easily replaceable when they become worn or dull.

  The fly cutter only uses a single cutter (sourced from a lathe) that can be adjustable for diameter. The fly cutter is also used at much slower speeds (300 – 400 rpm) than a face or shell mill. The advantages of using a fly cutter are that it leaves the best surface finish of any other facing method and allows you to change the size of the area you are facing.

  A face mills cutter may feature either a negative, neutral, or positive rake. This means the cutter is 90° perpendicular to the material's surface or at any other angle. A positive angle puts the leading edge of the cutter's face forward, "into" the cut, while a negative angle will feature a leading edge that "drags" through the cut. The positive angle gives you a sharper cutting surface but reduced tool

Figure 30: Various milling tools.

strength, while a negative angle is the opposite. A negative angle will allow you to use more force to cut and will give you a better surface finish, but at the cost of more heat and friction. The angle of the cutter is completely dependent on the material(s) involved, the depth and speed of the cut, and the machine's setup.

- **End Mill**. The end mill is a tool designed with cutters along both its sides and bottom. The term "end mill" usually refers to a flat bottom cutter, but the end mill comes in several varieties: flat, ball, bull, chamfer/radius, and dovetail. End mills can be used to perform a variety of milling operations: face, side, slot, plunge, and ramp.

  End mills may feature from two to eight cutting faces and flutes. Like drill bits, the number and twist rate of the flutes control material removal from the hole. A fast twist rate is designed to remove material faster for a faster feed rate. A slower twist rate is designed for softer metals where galling is concerned (aluminum or copper). A higher number of cutting faces and flutes is preferred for harder materials. End mills can also be right- and left-hand cutters, meaning they are designed to cut rotating clockwise or counterclockwise.

  The difference between end mills is the profile of the cut the end mill leaves. The flat mill features a flat bottom that leaves a right angle cut profile on workpiece edges and a flat bottom slot or hole in the center of workpieces. A ball end mill features a semi-spherical bottom cutting surface that will leave a flat-sided, concave radius bottom on the side of a workpiece and a concave bottom slot or semi-spherical bottom hole. A bull nose end mill features a flat bottom with radiused corners that cuts a flat bottom profile with radiused corners. Chamfer end mills feature an angled point bottom used to chamfer hard corners of edges and around holes. Radius mills feature a concave radius bottom that leaves a convex cut profile around edges of the workpiece. Radius mills are also known as corner-rounding mills.

  Dovetail cutters cut a profile similar to a trapezoid. They are used to cut slots intended as mounting points for sights or other parts such as lugs or mounts. Dovetail cutters will vary in cut depth, width, and sidewall angle. The two most popular wall angles for sights are 60°and 65°.

- **Boring Heads/Bars**. Boring heads and bars are used to enlarge the inside of holes or reduce the outside diameter of tubes or rods. The advantage of boring heads and bars is that they are infinitely adjustable, allowing you to cut a hole in any diameter or make a round outer profile. The boring head is the holder and is fully adjustable; the bar is the actual cutter. Boring bars vary in size and profile and are replaceable.

***Figure 31**: Tooling coatings.*

MATERIALS AND COATINGS

Tooling is generally made from a few different materials. Unlike drill bits, most tooling is manufactured to a higher standard as it is intended to make a more precise cut. Coatings are also used to increase the performance and extend the life of tooling.

Most tooling designed for use in a mill is made from three main materials and combinations of each.

- **HSS –** A type of tool steel that is much harder and heat-resistant than carbon steel. Designed to cut hardwoods, metal, and most other materials at a higher speed than high carbon steel.

- **Cobalt –** A type of HSS that incorporates cobalt. The cobalt makes it remain hard at higher temperatures. Designed for stainless steel and other hard materials. The hardness of cobalt also makes it brittle.

- **Tungsten –** A type of carbide (a metal with a molecular structure similar to a crystal). Hardest of all the bit types and fairly expensive, it is designed for any material. Tungsten carbide tends to be fairly brittle.

Coatings are used to protect tooling and prolong their cutting life. Coatings include various blends of titanium nitride (TiN, AlTiN, TiCN). TiN and its variants provide corrosion resistance as well as heat resistance and lubricity. The coatings provide greater performance and longer tool life (3X – 5X tool life compared with uncoated tooling).

VISES, CLAMPS, AND FIXTURES

There is a bunch of vises and fixtures that can be used to enhance the versatility of the mill. Vises and fixtures are used to hold the workpiece in a specific manner to perform various operations. Fixtures are used to hold multiples of the same workpiece in the same exact position and manner and are intended for high volume production work.

- **Milling Vise**. The precision milling vise is used to secure and align parts while machining. The vise uses a large screw to move one vise jaw to and away from another (fixed) vise jaw. The vise is mounted to the table of the mill with "T" nuts and leveled and trued before any work is performed. The milling vise may also sit on a swivel base that will allow the vise

Figure 32: A precision mill vise.

to rotate on the table or may tilt so you can set parts at an angle.[13]

- **Clamping Kit.** A collection of blocks, bolts, nuts, spacers, and hold downs used to secure the workpiece to the table while machining. A clamping kit will allow you to hold awkwardly shaped workpieces with ease, or secure your vise or other fixtures. Most mill tables use either ½ in., ⅝ in. or ¾ in. "T" nuts to secure the blocks and hold downs to the table. The blocks or "step blocks" are pairs of right angle triangles with teeth along the angled face. When the two angles' faces are mated to each other, the small teeth or "steps" allow adjustment of height of the blocks. The kit may include locating or reference pins that allow you to make your own fixtures for production work.

  The kit may also contain 1, 2, 3 blocks. They feature a series of threaded holes along both its face and sides. The 1, 2, 3 blocks can be used as parallels, spacers, or risers. They can also be bolted together and set at various angles to hold non-square workpieces. Because the 1, 2, 3 blocks are precision machined to within .0002 in. – 3 in., they can be used to pull measurements off of or to help tram the head.

- **Rotary Table/Rotary Indexing Fixture**. A rotary table is a vise that can be rotated, moving the workpiece into and around a spinning cutter. Unlike a vise that has a rotating base, the rotary table can be moved while the machine is running and is used to mill radiuses, arcs, and circles. Rotary tables are also used for indexing parts between cuts or operations. A handwheel (with micrometer dial) is used to rotate the table, which features a degree indicator and allows for precise adjustment and tolerances.

  The table can be mounted vertically or horizontally with a general clamping kit. The taper spindle of the table will allow you to use collets and chuck to hold a variety of parts. When set up vertically, the table can be used with a tailstock that can be used to center barrels or other round parts (for fluting or other machining). The tailstock helps with alignment and rotation and also secures and supports the workpiece. The tailstock is adjustable to ensure perfect alignment between the center of the tailstock and the table's spindle center. Theoretically, with all of the versatility of the mill, a rotary table, and some skill, you could machine a whole other mill.

- **Fixture/Tooling Plate**. A fixture plate is used to hold multiple pieces in the same exact manner for production work. The

[13] *Please note that you cannot move the vise while the machine is running. Any adjustments need to be made with the machine off. Make certain you tighten the vise's adjustment lock screws before cutting.*

face of the plate may feature a series of "T" slots or holes (possibly threaded) that provide multiple points of alignment. Pins or clamps and bolts can be used to precisely position workpieces over and over. The plate is typically secured to the table, but smaller plates may be held upright in the vise.

ACCESSORIES

There is a huge array of accessories that are used in various operations or setups. These accessories help hold different tooling, align workpieces, or measure tolerances. There are more accessories that are available than are listed, but these are the most common and most widely used.

- **Collet**. A collet is a type of collar or chuck used to hold and secure tooling in the spindle. It typically features a cylindrical inner surface and a tapered outer surface that matches the spindle and has evenly spaced slits along its circumference. When the collet is placed in the spindle, the drawbar draws the collet upward, forcing the collet's fingers to grasp the tooling. Collets are typically purchased in sets that will cover a broad range of tooling shank diameters. One collet will fit a few different size shanks. Collets can also be used on drill presses and lathes. The R8-style collet has quickly become the industry standard taper profile.
- **Sleeve**. Sleeves are used to adapt smaller diameter shanks to fit in larger collets or chucks. They feature cylindrical outsides of a larger diameter and an inner smaller diameter. The smaller diameter tooling is inserted into the sleeve and the sleeve into the chuck or collet. Sleeves may also be tapered inside and out for use with tapered shank tooling.
- **Chuck Adapter**. The chuck adapter is a specialty clamp designed to center and hold cylindrical objects like bits or other tooling. The chuck uses a series of jaws (3 – 6) arranged symmetrically around the inside of the chuck. When the sleeve

Figure 33: *Various accessories: drill chuck, collets, and a dial caliper.*

is turned around the body, the jaws will open and close, allowing you to secure and use different sizes of bits. The chuck has a spindle on its head that fits inside a collet and then into the mill's spindle. There are limitations to the size of bit most standard chucks can handle. You may have a ¼, ½, ⅝, or ¾ chuck. The number refers to the maximum size bit the chuck will accept. A ½ chuck will hold most bit sizes you will be using, but there are adapters that will allow you to use bits that are larger or smaller than your chuck is capable of accepting.

Edge Finder. An edge finder precisely locates the edge of the workpiece. It may be mechanical (spring-loaded) or electronic (the machine, edge finder, and workpiece complete a circuit) and will vary in its degree of precision. A mechanical edge finder is used while the spindle is spinning, while the electronic edge finder is used stationary. It works by spinning two concentric, spring-loaded cylinders, one (body) fixed in a collet in the spindle while the other (tip) is allowed to move freely. The tip is precision machined to a specific diameter (usually .200 in.). Once the edge finder begins to spin and touches off on the part, you will notice three distinct modes: orbiting, centered, and offset.

The edge finder's tip will orbit when it is moving freely, away from the workpiece. Once the edge finder comes in complete contact with the edge of the workpiece, the tip will spin in perfect concentricity with the body and the whole edge finder will appear to be one piece. Any further movement (as little as .0001 in.) will kick the tip off to one side of the workpiece. The area between perfect concentricity and kick out is going to be your edge within .0001 in.

- **Dial Indicator**. A tool used to measure small distances and amplify the readings. The indicator features a probe that, when depressed, turns a needle around a dial and shows distance traveled. Most indicators will show travel in increments from .00005 in. to .001 in. The indicator can be mounted to various shanks or may have its own base (sometimes magnetic) and articulating arm, allowing it to be placed in various locations. The dial indicator is an invaluable tool used for tramming the head, squaring the vise, checking for backlash, and runout, as well as setting up work and locating cuts.

- **Caliper, Micrometer**. Calipers and micrometers are fine instruments used for measuring. Calipers are used to measure internal and external dimensions while the micrometer is used to measure thickness or depth. The caliper may feature a dial similar to a dial indicator. The micrometer may feature a C-shaped body for measuring thickness or a T-shaped body for measuring holes. The caliper and micrometer provide measurement in increments from .0005 in. to .001 in.

- **Parallels**. Precision, rectangular blocks used to raise and support workpieces in the vise. Parallels come in pairs and are precision ground and lapped on all sides to within .0001 in. or less of each other. They can be used to raise workpieces or support and align uneven workpieces.

Maintenance Chart	
Every 8 hours of operation	Check cleanliness of ways and remove any debris. Check way lubrication. Check oil reservoir level.
Every 40 hours of operation	Thoroughly clean the machine of any chips, swarf, oil, coolant. Check oil and coolant reservoir (if applicable).
Every 160 hours of operation	Clean oil filter. Check electronics (contacts, switches, and connections) for dirt, oil, and water. Clean and tighten connector, if necessary. Check or fill oil and grease fittings.
Every 1000 hours of operation	Change oil or coolant. Check or replace drive belts or gears. Inspect bearing runout. Clean or replace way wipes.

***Table 1**: Suggested maintenance frequency for a mill.*

MAINTENANCE

Like any other heavy duty machine, the mill requires periodic maintenance to prolong the machine's life and preserve its precision. Each specific machine will have its own maintenance regimen. This is a general checklist of things to check based on machine usage. Regular maintenance will guarantee a long service life for your machine. Table 1 is a general maintenance guide; refer to your owner's manual for specific guidelines for your machine.

ADJUSTING GIBS AND WAYS

Gibs control the play and movement of the table, saddle, and knee on their prospective dovetail ways. Gibs are like adjustable wedges that sit between the moving and stationary surfaces. Tight gibs will ensure precise movement of the table/saddle/knee on the way and precise machining of the workpiece, but might cause binding in the movement. Loose gibs will allow for ease of table/saddle/knee but sloppy machining of the workpiece. Perfect gib adjustment would result in a table/saddle/knee that moves easily with zero slop.

To check if your gibs need to be adjusted, use a dial indicator. For example, if you are checking the table, move the table completely to one side of the machine. Mount the dial indicator near the opposite side of the table so that the probe is touching the side of the table, but no part of the indicator is on or touching the table. Holding onto the side of the table sticking out, put side load back and forth against the table and watch the indicator. If the gibs are loose, the indicator will move. Most machines have a small tolerance (~.0015 in.), but anything over manufacturer's specification and the gibs will need to be adjusted. This same procedure can be used for the saddle and knee.

Adjusting gibs is made fairly simple with the adjustment screw(s) near the table, saddle, ram, and knee. There is sometimes a certain order of operations when adjusting the gibs (X, Y, then Z or right then left), so refer to your owner's manual for specific instructions. Typically, you start by loosening the lock screws opposite of the adjustment screws. Tighten the adjustment screw a small amount. Move the table and feel for any resistance in the wheel. You want to tighten the gib enough to remove any play in the way but not so tight that you feel resistance or binding. Once the gib is adjusted, tighten the lock screw and check the feel of the table/saddle/knee. Adjust as necessary.

MEASURING RUNOUT

Over time, continuous use of the machine will cause wear on moving and spinning parts leading to runout. Also, variances in manufacturing can lead to runout of the spindle, holders, and tooling. Runout is basically any variance in the spindle's rotational axis that can lead to part dimensions being out of spec. Even if the spindle, collet, and tooling are all within .0005 in. – .001 in. of perfect concentricity, the three pieces combined could lead to a maximum runout of .003 in. If a part's tolerances have to be within ±.002 in., this setup would not work.

Measuring runout is fairly simple using a dial indicator. You can measure each component individually or together, right before starting a precision operation. Over time, you may begin to mark certain holders or tooling that do not meet specifications.

Start by mounting the indicator to the table with the probe touching the spindle/holder/tooling. Preload the indicator about .005 in. Set the dial to zero. Turn the spindle/holder/tooling and watch the indicator's movement. Note the amount of movement of the needle. Watch the indicator for the low spot. With the indicator set on the low spot, set the dial to zero.

Continue turning the spindle/holder/tooling and watch the indicator. The needle on the indicator should only move clockwise, revealing circular runout. Most machines start with a small amount (.0001 in.) of runout, which is acceptable. Runout greater than .002 in. may require replacement of the spindle/holder/tooling.

NOTES

NOTES

Chapter 4 - The Metal Lathe

Turning with a Lathe

The lathe is a machine that performs turning operations in order to make or shape round parts (such as barrels). The lathe holds the workpiece by one or two sides, depending on its length and operation. The workpiece is then spun around its axis, into the cutter, creating symmetry around the axis. This procedure is different than other machining operations because the part is spinning, while the cutter is stationary. This allows both external and internal surfaces to be turned to a specific profile. In a gunsmithing shop, the lathe is primarily used to chamber a barrel, contour a barrel, and also to make small parts such as firing pins. The lathe will also allow you to turn threads and make screws, and allow you to drill through the workpiece while the bit is stationary.

PARTS OF THE LATHE

Most lathes feature the same basic parts that function in the same manner, regardless of make or model. Knowing the parts of your lathe will help you safely operate and diagnose any issues that may arise.

Below is a list of parts for a basic lathe.

- **Headstock**. The headstock is the center of the lathe and is supported by and mounted to the bed on the ways and contains the spindle. The headstock also contains the pulleys and gears used to drive the head and the spindle speed selector. With the workpiece secured in the spindle, the headstock transfers torque from the motor to spin the part. The headstock is typically on the left side of the machine.
- **Motor**. The motor is the heart of the lathe and is used to drive the spindle through a series of pulleys or gears. It may spin at varying speeds while producing a specific amount of power. The lathe also uses the spindle speed selector to slow or accelerate the speed of the spindle even further. A minimum of 1.5 – 2 horsepower is recommended for turning operations in most metals, while 3 – 4 horsepower would be optimal. The motor may be hardwired to a power source or use a more convenient 3-prong 220 volt plug.
- **Tailstock.** The tailstock is used to help support or secure longer workpieces. It is supported by the bed's ways, but moves freely along the X-axis. The upper portion of the tailstock contains the

Figure 1: The lathe.

spindle. The tailstock moves along the X-axis toward and away from the headstock and can be locked in at any point. The spindle, which does not spin, also moves along the X-axis independent of the tailstock by way of adjustment wheel. The tailstock can also be equipped with a center to turn between centers and can be adjusted to turn tapers.

- **Spindle**. The spindle translates horsepower and torque from the motor/head into the chuck, faceplate, or drive plate. There are various ways for the spindle to hold the workpiece from collets and chucks to face and drive plates. The spindle features a through hole that will allow you to use workpieces that are longer than the machine itself. The accuracy of the spindle's construction and its rigidity, as well as the quality of the bearing system of the spindle, is key to the machine's long-term performance and precision. The bearings must be able to hold up to the abuse of the power and load forced onto them. The spindle in the headstock is known as the "live center" because the workpiece is being held and driven.

- **Tailstock Spindle**. The tailstock spindle is like the headstock spindle except that it is not powered and does not spin. The tailstock spindle is in perfect alignment with the headstock spindle to ensure that parts that rotate between them do so in perfect concentricity. Like the headstock spindle, the tailstock spindle can hold the workpiece in various ways from collets to chucks. The tailstock spindle can also hold various cutters to bore and thread internally, or drill bits for drilling. It can hold a center to position workpieces that need to be turned between centers. The tailstock spindle is also known as the "dead center" because it does not rotate and is not powered.

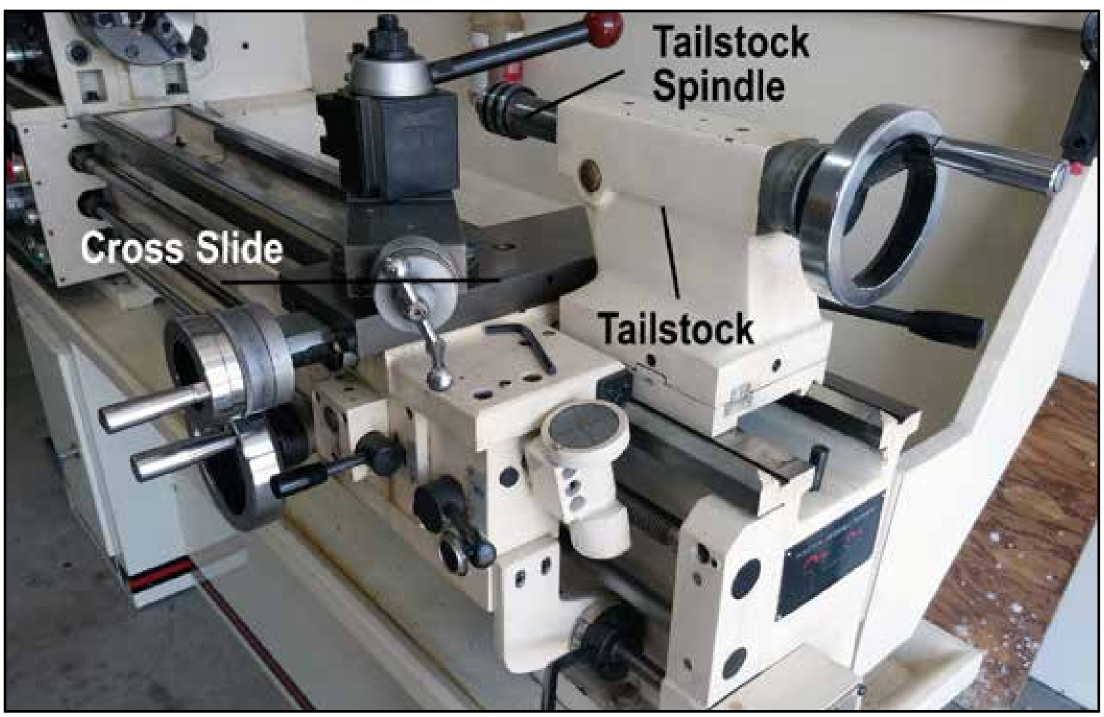

Figure 2a: *Parts of a lathe.*

- **Apron**. The apron is part of the assembly that makes up the carriage. It is mounted to the front of the saddle and houses the gears and controls used to move the carriage either manually or automatically across the bed. The lead screw and feed rod pass through the apron and provide a means for movement. The apron also houses the assembly that controls the screw cutting feed (threading). When the half nut lever is closed, the lead screw engages for threading.
- **Saddle**. The saddle is the second part that makes up the carriage assembly. It sits on top of the bed and provides a mounting point for the apron (side) and supports the cross slide (top).
- **Cross Slide**. The cross slide sits on top of the saddle and moves along the Y-axis. It is controlled by a cross feed handwheel. The cross slide also supports the compound rest.
- **Clutch/Brake**. The clutch/brake allows you to stop the machine quickly. It can be disengaged quickly if your setup is incorrect or dangerous and can prevent machine damage. The clutch also prolongs motor life by negating the need to start and stop frequently.
- **Spindle Speed Selector**. The spindle speed selector allows you to change the speed of the spindle to suit your specific needs. Depending on the machine, speed may be controlled by cone or step pulleys, pulleys with back gear, or a complete gear train. Speed control may also come from an electric rheostat-like control.
- **Quick Change Gearbox**. Some machines may be equipped with a quick change gearbox. The quick change gearbox is used to change the feed rate of the cutter and pitch of the threads being cut. Through a series of gears or pulleys, the quick change gearbox controls the speed of the spindle and the feed of the tooling across the workpiece. The various settings of the machine will allow you to cut a range of threads, both imperial and metric. The controls may also be set to cut at different speeds: slow, medium,

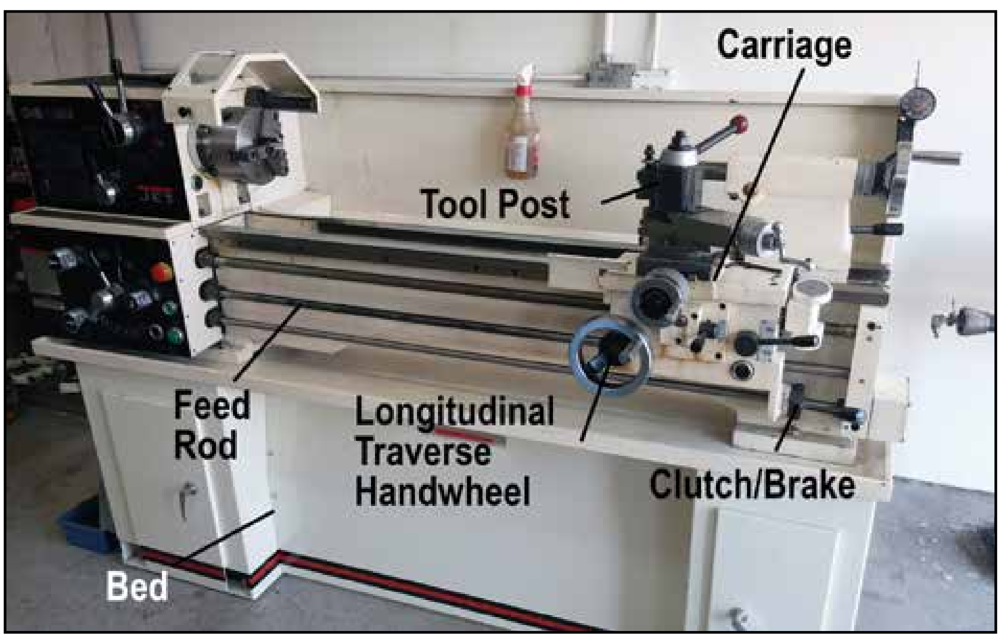

Figure 2b: *Parts of a lathe.*

Figure 2c: Parts of a lathe.

and fast. The speed control allows you to cut deep and course (slow) and progress to shallow, fine finish cuts (fast). The quick change gearbox is advantageous because it saves a lot of time in the initial setup for cutting different thread pitches.

- **Split Nut Control**. The split nut control engages the lead screw to provide a drive for threading. Once the split nut control is engaged, the two halves of the nut are clamped down against the lead screw, which moves the carriage at a specified rate. The gear ratio of the machine will dictate both the rate at which the lead screw moves and the pitch of the threads.
- **Carriage**. The carriage is an assembly composed of the apron, saddle, and compound rest. It moves along the ways in the X-axis manually by carriage handwheel or by power feed.
- **Ways**. The ways are the precision guide rails that the carriage and tailstock ride along. They are precision ground into the top of the bed and run parallel with the axis of the spindle. The ways stop just short of the headstock to allow clearance for large diameter parts.
- **Compound Rest**. The compound rest sits on top of the cross slide and holds the tool post. The compound rest rotates on its base and provides another axis of adjustment for cutting tapers and threads. The compound rest also allows a small amount of adjustment in the XY-axis (perpendicular and parallel to the cross slide) via a feed screw and wheel. The compound rest adjustment is much finer and precise than the cross slide. The compound rest is also known as the top slide.
- **Tool Post**. The tool post is used to hold the cutters. It comes in a few varieties: lantern, four-way, and quick change. The lantern style features a profile shaped like a lantern. There is a window through the center of the holder for tooling to pass through. A bolt on the head of the tool

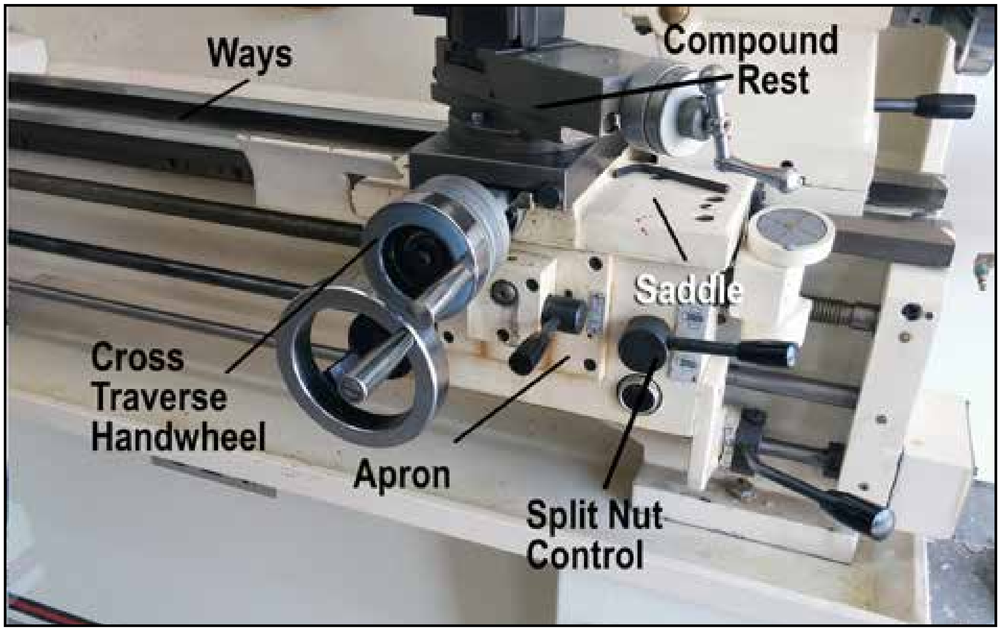

Figure 2d: Parts of a lathe.

holder that passes through the middle of the holder is used to clamp down on the tooling. The main advantage of the lantern style is that its small profile will not interfere with larger workpieces and the tooling can be shimmed to attain center height; the main disadvantage is that they tend to flex under heavy use.

The four-way tool post will allow you to hold multiple cutters (1 – 4) along its four sides. This is not always practical as some of the tooling may come in contact with the workpiece. It is also difficult to shim tooling in a four-way post.

The quick change tool post is the most versatile of the holders. It consists of a body and individual holders that affix to each other with dovetail mounts. The post has mounts on two sides, allowing quick change for side (profile/contouring) and face (boring/drilling) turning. The quick change post also allows you to shim each cutter in its respective holder, so each time you change tooling, they are already adjusted to center. The post may have a self-centering feature instead.

- **Longitudinal and Transverse Feed Control**. The longitudinal and transverse feed controls are the power for automatic controls. The longitudinal feed control is used to manipulate the power feed of the carriage in the X-axis of travel. The transverse feed control is used to manipulate the cross feed in the Y-axis of travel. The feed controls are adjustable to move the carriage and cross feed at specific rates (distance over time).
- **Lead Screw**. The lead screw is a long, threaded rod used for threading. When the split nut control is engaged, the lead screw is tied to the spindle at a specific ratio based on the current gearing, and moves the carriage along the ways. If the spindle and lead screw are moving at a 1:1 ratio, the threads being cut are equal to the threads of the lead screw. If the ratio is 2:1, then there are twice as many threads being cut as the lead screw features.
- **Feed Rod**. A long (nonthreaded) rod that controls the feed of the carriage and cross feed. The feed rod is powered by the

spindle and its rate (distance over time) is controlled by gears in the headstock. It is engaged and disengaged by way of clutch(s). The feed rod powers both the longitudinal and cross feed controls.

- **Bed**. The bed is the foundation of the lathe. It supports the headstock, carriage, and tailstock. Precision ways machined into the top of the bed provide guides for the carriage and tailstock to move on. The bed may also feature a gap near the headstock to allow clearance for larger diameter workpieces. The bed is typically made of cast iron to provide stability for the machine and features adjustable leveling screws on its base to allow for leveling the machine.

OPERATIONS

Although not as versatile as the mill, the lathe is capable of performing many operations. In a gunsmithing shop the lathe is best suited for contouring and chambering barrels, making firing pins, and other cylindrical parts. The versatility of the lathe is enhanced by the tooling and accessories being used.

- **Turning**. Turning is the process of cutting a cylindrical workpiece by way of lathe. It includes such operations as facing, cutoff, tapering, contour/form turning, grooving, and chamfering. Facing is the process of cutting a flat face on the workpiece. It is used to cut a workpiece to a specific length or to provide a perfectly square end (perpendicular to the rotational axis) used for measuring and layout. Cutoff is simply cutting off the end of a workpiece to length or in preparation for facing. Tapering is the process of creating a uniform, graduated increase or decrease in the diameter of the workpiece. It produces cone-shaped profiles. Contour/form turning is the process of cutting a specific profile into the workpiece, typically with a cutter with a mirrored profile. Chamfering is the process of cutting workpiece edges to produce an angled corner.

- **Threading**. Threading is the process of cutting threads onto the internal or external surface of the workpiece. A thread is a helical groove cut into the inside of a hole or the outside of a rod or cylinder. External threads on a cylinder or rod are known as "male," while internal threads inside of a hole are known as "female." Threads also have a major and minor diameter. The major diameter is measured

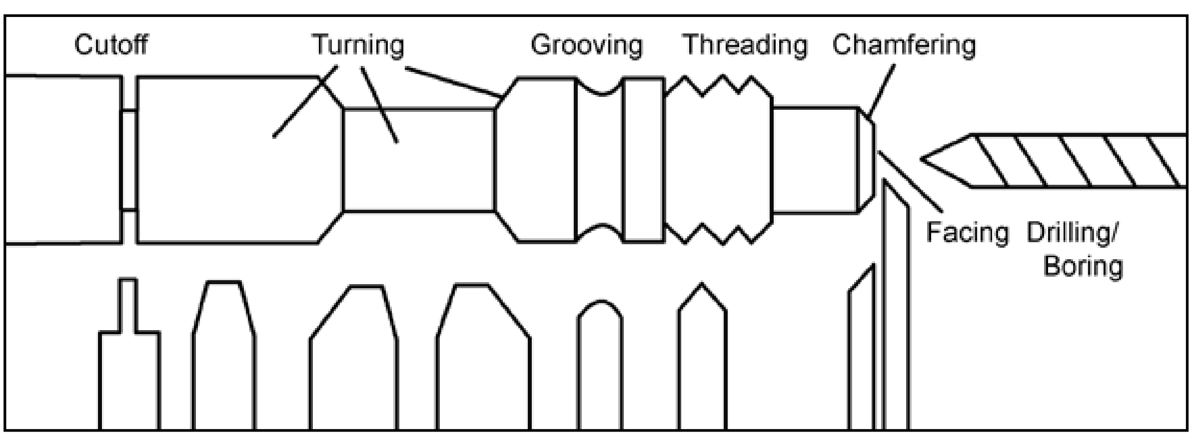

Figure 3: Turning operations.

from peak to peak of the grooves, while minor is measured from valley to valley. Threads can also be right- and left-hand. Right-hand threads turn clockwise while left-hand turn counterclockwise when looking at the workpiece. The threads may also have a sharp (triangular), radiused, or square profile.

Thread pitch is the distance from peak to peak along the axis parallel to the workpiece's center. The pitch is measured as a rate of threads per inch. For example, if there are 28 peaks per inch, the thread pitch would be 28 tpi (threads per inch).

- **Boring**. Boring is the process of enlarging a preexisting hole. It is also used to achieve greater precision in the final diameter of the hole or to cut tapered holes. Boring ensures holes are straight through their entire length and is typically used to make larger holes than drilling or reaming.

- **Drilling**. Drilling on a lathe is very similar to drilling on a drill press, except for the bit is stationary while the workpiece is spinning. With the use of a drill chuck adapter you can even use standard twist drill bits. The same types of drilling are also possible: through, stop and spot. Depending on the type of cutter/bit used, the bottom of the hole may be flat or conical. Spot drilling creates a conical dimple on the surface of the material used to center and start a twist drill in a precise location and prevents walking.

- **Knurling.** Knurling is the process of cutting or pressing a pattern into the surface of a workpiece. The design may consist of straight, angled, or crossed (diamond) lines. Knurl rolling is the most widely used technique because of ease of accomplishment. Rolling is accomplished with the use of a hardened die and holder being rolled across the surface of the workpiece. The disadvantage of rolled knurling is that the die must match the diameter of the workpiece to ensure even spacing around the workpiece. Cut knurling is accomplished in a manner similar to threading.

SETUP

Thoughtful planning before setting up your lathe will save you many headaches down the road. Your first consideration is the location. You want to place your lathe in an area that will allow you to access the whole machine and allow you to work on longer pieces without bumping into things. You also want to consider your power source: is your location close enough to an outlet or will you need an extension cord?[1] Once you have your location, you will need to true the mill.

Start by leveling the bed. Most workshop floors tend to be fairly level, so this is usually as simple as setting the lathe in place. If the floor is not level, you will need to adjust the leveling screws on the base of the bed until it is level. Make sure you level the bed on both the X (side to side) and the Y (fore and aft) axis to ensure that it is plumb and level and to prevent bed twist.

[1] *Be aware you may also have to ground the motor to prevent damage or electric shock. Please refer to your owner's manual for instructions for your particular model.*

You can check the level of the bed with the help of an alignment bar and dial indicator. The alignment bar is a precision-machined rod that is perfectly concentric and true within .0001–.0002 in. along 12 – 16 in. of its body. It may also have pilots machined into its ends to measure between centers, or use tapered ends that fit into the spindle. You will need to check the alignment of the headstock and tailstock as well as alignment between centers.

First, you need to align the headstock. To align the headstock, mount the alignment bar in the spindle. If you are using a 3- or 4-jawchuck, you will need to place the alignment bar in the chuck with 10 – 12 in. sticking out and secure it but do not tighten it. To center the bar, bring the carriage close to the headstock and mount a dial indicator to the front of the carriage with the indicator's stem running parallel to the cross feed and centered on the alignment bar. Turn the spindle and watch for the high and low spot. Loosen the chuck jaw closest to the low spot and tighten the chuck jaw opposite. Rotate the spindle and continue to loosen and tighten the jaws until the needle does not move. The alignment bar is now centered in the chuck. Set the dial indicator to zero.

Now you can check bed twist. Run the carriage away from the headstock toward the end of the alignment bar. Note any change in the indicator. Clockwise movement of the needle means the alignment bar is angled toward the indicator (the front of the machine); counterclockwise means the bar is angled away toward the back of the machine. If the alignment bar is angled toward the front of the machine, the front of the machine will need to move up; and if the bar is angled back, the rear of the machine will need to come up. All adjustment should be made on the tailstock (right) side of the machine. If the front needs to be raised, adjust the front right leveling screws and watch the indicator; if it needs to be lowered, adjust the right rear screws. Adjust the screws until the dial reads zero. Your horizontal alignment is complete; now you need to check vertical.

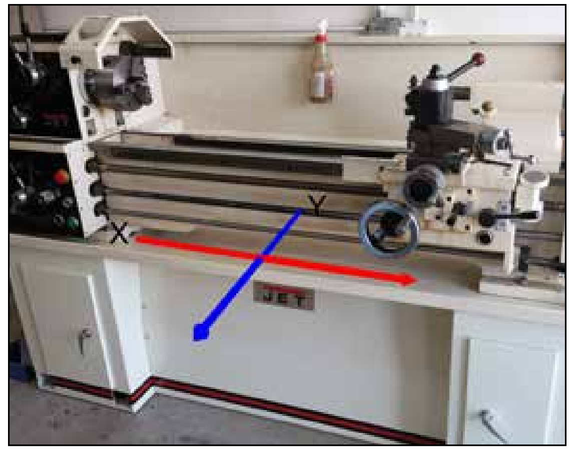

Figure 4: Lathe setup.

Checking vertical alignment is the same as horizontal except the stem is arranged vertically under the alignment bar. Return the carriage to its position by the headstock. Preload the indicator and set the dial to zero. Move the carriage to the right of the machine and note any movement of the needle. Clockwise movement of the needle means the bar is angled down and counterclockwise movement means the bar is angled up. Adjust both the front and rear screws an equal amount to compensate for any bed flex. After every adjustment you may need to check the horizontal and vertical adjustment to ensure everything stays level. The bed and headstock are now level and true. Now you can level the tailstock.

To level the tailstock you will need to set the alignment bar between centers. The headstock is already level, so all your adjustments will be made to the tailstock. Move the carriage toward the tailstock and mount the dial indicator. Preload the indicator and set the dial to zero. Rotate the spindle and watch the needle. Note the high and low spots. Adjust the tailstock until the alignment rod spins true. Check the tailstock alignment with the spindle extended and retracted to verify there is no angular

misalignment. Now that the tailstock is aligned, the lathe (bed, headstock, tailstock and carriage) is all level and true.

Before start up, make certain the lathe has been properly lubricated. Refer to your owner's manual for specific lube points and any other model-specific setup. You may also consider wiping the headstock, tailstock, carriage, ways, and any other unfinished metal with a light coat of oil to prevent rust. You will also want to wipe the ways of any chips or dirt and debris. If the machine is equipped with way wipes, remove and clean them. For now, the machine is set up and ready for use.

TURNING

Now it's time to turn a part. It seems like a simple task, but when performed correctly, the concentricity of the part is the result of many carefully considered variables. Where are the cuts going to be? What material are you cutting into? You should develop a mental or physical checklist of the steps involved in turning. For the purpose of this exercise, we will discuss how to thread the muzzle of a barrel in preparation for a flash hider or brake.

- **Location and Layout**. Planning out the location of your threads is one of the most important steps. Often, you only get one chance to cut threads in the correct location, so there is no room for error or you may find yourself buying a replacement barrel. You will need a handful of tools and materials.

Various calipers, rules, squares, combination squares, protractors and levels along with scribes, and layout dye are all used to help locate the threads. The barrel is first covered in a thin coat of layout dye that is allowed to dry for several minutes. Using drawings or plans and known measurements of your workpiece, you can start to layout your threads. You will have to take into account whether or not the muzzle brake requires a shoulder or shims and if a crush washer or lock nut will be used. For the purpose of this exercise, we will be cutting ½ x 28 (.5000-28-UNEF-2A[2]) threads, which is a very common .22 caliber thread pitch.

Use rules, squares, and protractors and scribes to "draw" the layout on the surface of the workpiece (not specifically the threads, but length of threaded area, thread relief, and the shoulder). Use the straight edge of the rules and squares to scribe your lines. Use known square or true edges to measure against. Measure several times to ensure you are marking the workpiece with the correct dimensions.

- **Material**. Knowing your material is also a big part of turning properly. Nine out of ten times you can use any HSS cutter to cut your workpiece. On the tenth time, however, you may have to cut a hardened steel workpiece and your average high speed steel (HSS) cutter may not be enough. Modern cutters have been specially developed for the material they are intended to be used on, and in the case of a hardened part, carbide would be best suited. For the purpose of this exercise, we will be using a carbide-tipped, 60°, single-point cutter.

Knowing your material will allow you to choose the cutter that will work best for the job at hand. Once you have selected the cutter that will work best, you can set the speed of your spindle. Most machines feature some means of speed adjustment in several ranges. A good rule of thumb is you want the cutter to be harder than the workpiece and to move as fast as necessary to provide

[2] *UNEF-2A is a designation of the Unified Thread Standard (UTS) for "extra fine" 60° threads.*

a smooth, clean cut. Small or shallow cuts and soft materials usually require high rpm, while large diameter, deep cuts, or hard materials use lower rpm. Cutting too slow or too fast will put excessive strain on the tooling and workpiece and will leave a sloppy, burred, or chipped finish.

It would be smart to have a machinists' handbook on hand if there is ever a question of what type of cutter to use at a given speed for a specific type of material. These handbooks can be very valuable to any machine shop, as they contain figures for cutting speeds and feeds for various materials and types of cutters, as well as other info valuable to machinists, engineers, draftsmen, and toolmakers. Assuming the barrel is made from high carbon steel and we are using a carbide cutter, the spindle should be moving as slowly as the machine will allow.

- **Securing and Truing**. You want to secure your cutter and workpiece and true and square the workpiece while cutting to ensure the most precise, cleanest threads possible. Any movement of the cutter or workpiece while cutting will cause the threads to become out of spec or irregular, or could potentially fling the workpiece or cutter across the room, which could be extremely dangerous. Securing the cutter is fairly simple. If you are using a quick change tool post, simply place the cutter in the holder and tighten the locking bolts. You will need to set the cutter's height to centerline, but that can be done after the barrel is secure and true.

Securing the barrel is fairly simple. Truing the barrel is also fairly simple and can be done simultaneously while securing the barrel. You will need a 3- or 4-jaw chuck and a dial indicator and some type of protection for the barrel's finish (tape works well). Set the barrel in the chuck so that only 2 in. – 3 in. of muzzle are sticking out from the jaws. Tighten the jaws until they are barely touching the barrel. Move the carriage toward the headstock. Mount the dial indicator

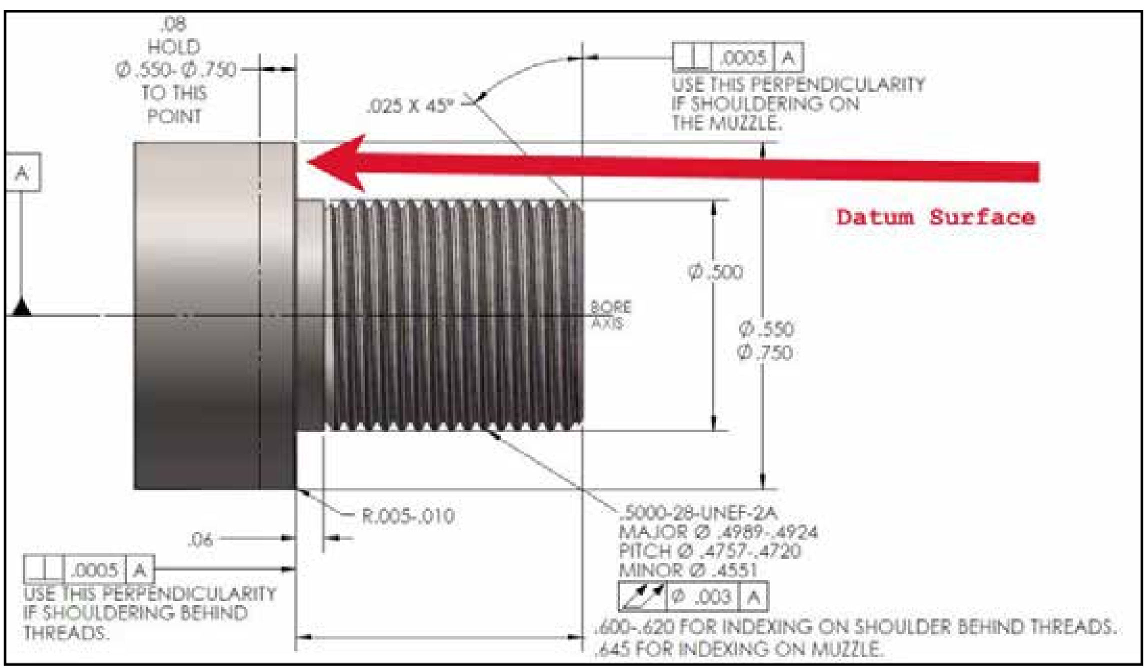

***Figure 5**: Sample ½ x 28 thread drawing.*

near the tool post with the stem inside the bore.[3] Rotate the spindle and watch the needle.[4] Find the high and low spot inside the bore. Loosen the jaw closest to the high spot and tighten the jaw closest to the low spot. Continue to turn the spindle and adjust the jaws until the barrel spins true. Tighten the jaws down and recheck alignment. The barrel is now secure and true.

Now you can center the cutter on the barrel (or slightly below). This is fairly simple and does not need to be super precise for threading. All you need is a straight metal rule. Pinch the rule between the cutter and barrel, making sure you do not use too much force. Looking down the bed from the headstock (line of sight parallel to the X-axis), the rule should be sticking straight up, perpendicular to the Y-axis. If the cutter is not near centerline, the rule will lean right (cutter is too low) or left (cutter is too high). Use the knurled nut on the top of the tool post to adjust the cutter's height.

Once the cutter's height is set, you need to square the cutter to the barrel. This is easily accomplished with a specialty gauge called a "fishtail" or center gauge (specifically designed for 60° threads). Start by setting the compound rest at an angle. You want to rotate the compound rest so that the cutter is angled toward the headstock. Since we will be using the compound rest to advance the cutter, we want it set at an angle so the leading edge of the cutter is performing the cutting (as opposed to the cutter coming in perfectly straight and cutting with both edges at once and potentially breaking the tip). Since we are cutting 60° threads, we will want to set the compound to 29.5° off the Y-axis angled toward the headstock. This will allow us to cut 60° threads to depth by cutting only one angle, reducing strain on the tooling, and leaving a better finish.

Now you can square the cutter to the workpiece. Place the center gauge flush against the barrel and move the cutter toward the V-notch on the side of the gauge. Loosen the tool post lock screw and rotate the cutter until it sits perfectly in the notch. The cutter is now centered and square. You are almost ready to cut.

Lubricant/Coolant. Some materials and processes may require some type of lubrication or coolant. The lube or coolant serves two purposes. First, it keeps the cutter cool, which prolongs tool life and cutting surfaces. Second, it aids in clearing chips from the cut. Every machinist has a lube or coolant he or she swears by. Cutting fluid is most commonly used, but motor oil, mineral oil, vegetable oil, kerosene, lard oil, or even dish soap may be used as substitutions.

Aluminum, brass, bronze, and copper (nonferrous) will typically use the same type of lubricants (soluble oil, kerosene, or lard oil) while ferrous metals (iron and various steels) will use soluble oil, sulfurized oil, lard oil, or mineral oil. The type of oil used for specific materials may change with the operation being performed. You may also find blends of different oils and coolants may work better for certain applications.

There is another school of thought that using oil for cutting is counterintuitive. Because oil is used to make two surfaces slide against each other, it is believed the tooling will not cut as effectively as it would without lube. You may have to test certain combinations of materials, tooling, and lubes to find what works best for you. Regardless what you use, sharp tooling will always give you the best results.

- **Safety**. You are almost ready to thread the barrel, but first you need to do a last minute safety check. Make certain both your cutter and part are secure and the work area is clear of anything that may

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[3] *Using the bore to center the barrel is the most precise method to ensure that the bore of the muzzle brake is in perfect concentricity with the bore of the barrel. This insures the greatest accuracy and performance of your muzzle device and prevents potential baffle strikes.*

[4] *The needle will jump regularly .001 in. – 0 .002 in. every time the contact point rolls over a land.*

touch the cutter or spindle and workpiece while spinning. Also, make sure the feed wheels are free from obstructions. Remember to check yourself for clothes, jewelry, gloves, or hair that may become caught in the machine. This is your last chance to prevent damage or injury, so be certain you go over your safety checklist. This may seem like you are being overly cautious, but it only takes a small lapse in judgment or procedure to lead to disaster.

- **Threading**. It is finally time to cut threads, assuming your muzzle is the appropriate diameter. For ½ x 28 threads, the muzzle should be no more than .5 in. (the major diameter for this pitch is .498 in.). If the muzzle is larger than .498 in., you will need to turn the barrel. Replace the cutter with a turning cutter. Measure the current diameter of the muzzle.

For example, if the current diameter is .525 in., you will need to remove .027 in. of material. This does not mean moving the cutter .027 in. deeper. Any amount of cutter movement is translated to twice the depth of cut (cutting both sides of a rotating piece). To remove .027 in. of material, you will only need to move the cutter .0135 in.

Move the cutter so it barely touches the barrel (back out the compound and use the cross slide for gross alignment and use the compound for fine adjustment). Set your compound dial to zero once it touches the barrel. Move the carriage so the cutter just passes the barrel.

Use the compound feed wheel to advance the cutter to the desired cut depth. You could probably turn the barrel down in one pass, but you should split the passes into a roughing pass of about .010 in. followed by a pass of .0025 in. and a shallow finishing pass of 0.001 in. Turn the machine on and use the apron feed wheel to move the cutter through the cut. Stop at the shoulder mark you made during layout. Stop and return the compound to zero. Move the apron back to just ahead of the muzzle. Turn off the machine and measure to verify the final pass. You should now be at .505 in. (.525 in. – .020 in. cut). Make two more passes with the compound set to .0125 in. and .0135 in. Measure between passes to ensure you are cutting the correct depth. You should now be at .498 in. muzzle diameter.

You may also want to cut a thread relief or it may be required. A thread relief is a groove at the back of the threads just before the shoulder. It is typically the same diameter as the minor diameter of the threads or smaller. The thread relief provides an area to stop the cutter in without crashing into the wall.

Now you can begin cutting the threads. Remove the turning cutter from the holder and insert the thread cutter and align it (same procedure as before). The following directions are fairly general as the brand and type of machine used will vary slightly in operation and controls. Check your owner's manual for specific directions and settings.

Figure 6*: Quick change gear chart for thread pitches.*

First, you will need to set the gear box. If your machine is equipped with a quick change gearbox, this is easily accomplished with a few knobs and levers. There should be a chart in your owner's manual or directly on the machine that shows the settings needed for a specific thread pitch. There should also be a separate chart that shows thread dial start points for specific pitches. Set the levers and knobs to the correct settings for your thread pitch. Make sure to tap the "jog" button before turning the machine on. With some machines the thread dial is constantly on; with others you may have to engage it.

Touch the cutter off on the barrel and set your compound dial to zero. Set your carriage so the cutter is just ahead of the muzzle. Next, set the depth of the cut on the compound. The major diameter of the threads is .4989 in. and the minor is .4551 in. This means that each thread is .0219 in. deep (.(.4989 in. - .4551 in. = .0432 in./2 = .0219 in.). You will want to take several passes starting with a roughing pass followed by progressively shallower cuts. The first pass should be around .020 in., so set the compound out .010 in. (any compound movement is magnified X2).

***Figure** 7: Cut threads.*

Turn the machine on and watch the threading dial. Make certain you engage the half nut at the same threading dial marking every time so that you start the threads in the same place every time. Once the dial reaches your start point, engage the half nut and watch the cutter. The cutter will progress forward, cutting the threads onto the muzzle. It is important that you place all of your attention on the machine. If you do not disengage the half nut when the cutter reaches the relief, the cutter will crash into the shoulder and ruin your part. Once the cutter has reached the relief, **DISENGAGE THE HALF NUT**. Move the compound back to zero and move the carriage back to your starting point. Your threads should now be .020 in. deep, leaving .0019 in. left to cut. Set your compound to .0105 in. (making a .0210 in. cut) and make another pass.

If you have the muzzle device on hand, you can check fitment at this point. The muzzle device may start but be very hard to turn. Set your compound to make another pass of .0107 in. (bringing the threads to .0214 in. deep). Check the muzzle device again. If the device threads onto the muzzle with little to no resistance, you are done. If it is still tight, make another pass with the compound set to .0109 in. (.0218 in. deep). Continue to check and cut until the muzzle device threads onto the muzzle with little to no resistance.

Once the muzzle device is fit, you will need to chamfer the leading edge of the muzzle. Change out the thread cutter for a chamfer cutter. The drawing shows a 45° chamfer .025 in. wide. Using a 45° chamfer cutter makes quick work of the chamfer. Set the compound parallel to the bed and the cutter perpendicular to the barrel. Touch the cutter to the outside edge of the muzzle. Turn the machine on and advance the compound .025 in. You can clean any burrs with fine-grade steel wool. You have now threaded the muzzle with relief and chamfer.

Tooling and Accessories

There are many tools and accessories that you can use to perform various operations that further increase the versatility of the lathe. Knowing what accessories are available will allow you to select the best tools for the job at hand.

TOOLING

There is a huge array of tooling of different sizes and profiles, made from different materials for different materials, that all serve to complete one specific purpose: cutting. Using the correct bit for your job will ensure the smoothest operation. Lathe cutters are called tool bits, single-point cutters, or just cutters. Lathe cutters also come in right- and left-hand configurations. Right-hand cutters cut from right to left, while left-hand cutters cut from left to right. Many of the aspects of lathe bits are similar from type to type; typically, the only difference is the tip profile and cut profile.

- **Cut-off**. The cut-off cutter is used to cut off the end of a workpiece or to cut the workpiece into pieces. The tip of the cutter is typically square but may also be pointed (and doubles as a groove cutter). The cut-off cutter can be solid HSS or carbide or may use an HSS body with a carbide tip insert.
- **Turning**. Turning cutters are used to reduce the overall diameter of the workpiece. They come in a fairly large variety of bits, considering they are all serve one purpose. The cutting face profile is greatly dependent on the process you are performing. If you are rough turning or making finish passes, the cutter's profile will vary. The type of material being cut will also affect the cutter's face. Roughing cutters typically feature a radiused cutting tip. A round tip will withstand more cutting force than a pointed tip and therefore will last longer and be able to cut deeper. A finishing cutter will usually have a pointier tip than a roughing cutter, but the end of the point will still be slightly radiused. The slight radiusing of the tip will provide a better surface finish and prolong tool life.
- **Facing**. Facing cutters are used to cut the end or "face" of the workpiece to provide a perfectly flat, square side. The profile of the facing cutter is typically more sharply pointed than turning cutters. The facing cutters also have a more extreme relief angle so only the tip of the cutter touches the face and the rest of the cutter does not drag on the surface.

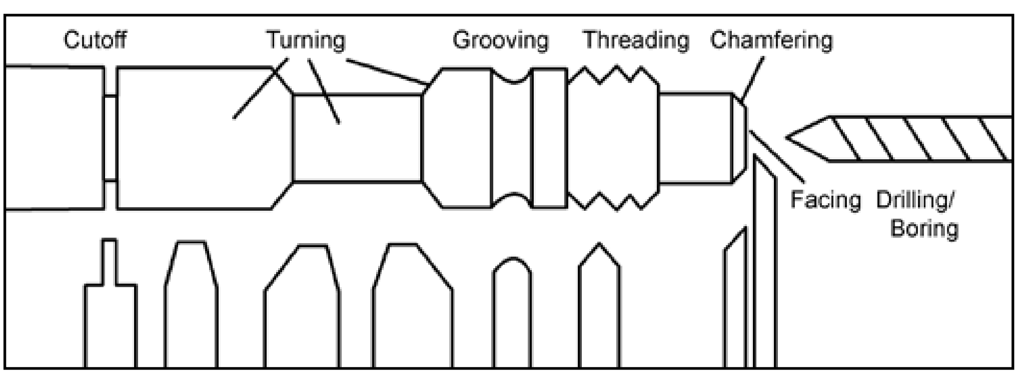

Figure 8: Turning cutters.

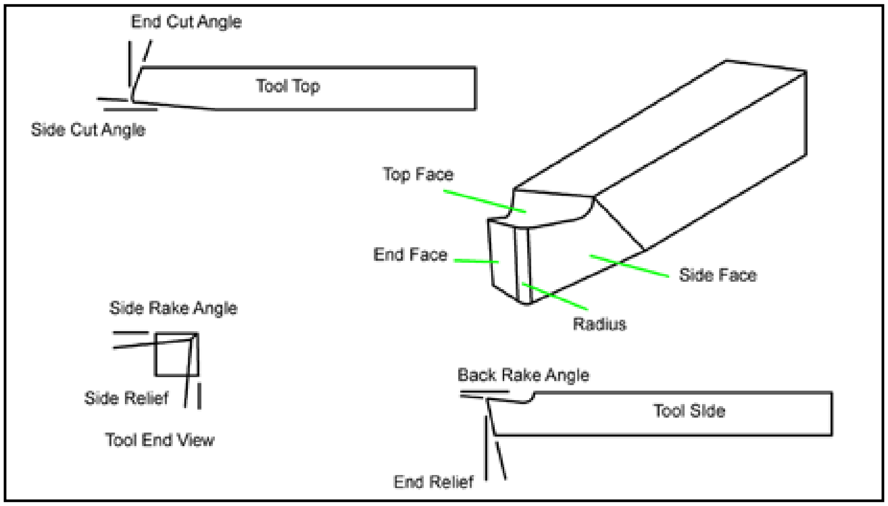

Figure 9: Cutter profile.

- **Grooving**. Grooving cutters are used to cut grooves around the circumference of the workpiece used for O-rings or other fittings. The profile of the grooving cutter will vary with the profile of the groove that is required. The grooving cutter features a round cutting face and is a type of form cutter that is used to cut a specific shape into the workpiece.
- **Threading**. Threading cutters are used to cut threads. The profile of the thread cutter is typically a 60° point with no radius. There are also thread cutters that may feature a radiused or square(ish) profile. Threading cutters are also a type of form cutter used to cut a specific profile into the workpiece.

Much of the turning cutter's profile is also dependent on the material being cut. There are a few critical angles required for proper cutting. The side, end, and top faces are all critical to the cutter's performance. There are also relief angles that are required to prevent rubbing or wear on the tool or workpiece. Table 1 is a chart of the most common profiles based on material.[5]

COMMON PROFILES BASED ON MATERIAL				
Material	Side Relief	End Relief	Side Rake	Back Rake
Aluminum	12°	8°	16°	35°
Brass	10°	8°	5° – -4°	0°
Bronze	10°	8°	5° – -4°	0°
Cast Iron	10°	8°	12°	5°
Copper	12°	10°	20°	16°
Steel	12°	8°	12° – 18°	8° – 15°
Tool Steel	10°	8°	12°	8°
Stainless Steel	10°	8°	15° – 20°	8°

Table 1: Common cutting profiles based on material.

[5] *This is for grinding your own HSS cutters.*

MATERIALS AND COATINGS

Cutters are generally made from a few different materials. Most tooling designed for use in a mill is made from three main materials and combinations of each. Coatings are also used to increase the performance and extend the life of cutters.

- **HSS** – A type of tool steel that is much harder and heat resistant than carbon steel. Designed to cut hardwoods, metal, and most other materials at a higher speed than high carbon steel.
- **Cobalt** – A type of HSS that incorporates cobalt. The cobalt makes it remain hard at higher temperatures. Designed for stainless steel and other hard materials. The hardness of cobalt also makes it brittle.
- **Tungsten** – A type of carbide (a metal with a molecular structure similar to a crystal). Hardest of all the cutter types and fairly expensive, it is designed for any material. Because of cost, most cutters use an HSS body with a carbide tip. Tungsten carbide tends to be fairly brittle.

Coatings are used to protect cutters and prolong their cutting life. Coatings include various blends of titanium nitride (TiN, AlTiN, TiCN). TiN and its variants provide corrosion resistance as well as heat resistance and lubricity. The coatings provide greater performance and longer tool life (3X – 5X tool life compared with uncoated tooling).

ACCESSORIES

There is a huge array of accessories that are used in various operations or setups. These accessories help to hold different workpieces and align them, setup and hold cutters, and make sure everything is square and plumb. There are more accessories that are available than are listed but these are the most common and most widely used.

- **Chuck**. The chuck is a specialty clamp designed to center and hold cylindrical objects like barrels or other workpieces. The chuck uses a series of jaws (3 – 6) arranged symmetrically around the center of the chuck. There are limitations to the size of bit most standard chucks can handle. Depending on the size of your machine, you may have a 4 in., 5 in., 6 in. or larger chuck. The number refers to the maximum size bit the chuck will accept. A 4 in. chuck will hold most workpieces you will be turning, but there are adapters that will allow you to use workpieces that are larger than your chuck is capable of accepting.
- **Collet**. A collet is a type of collar or chuck used to hold and secure tooling in the spindle of the tailstock. The collet typically features a cylindrical inner surface and a tapered outer surface that matches the spindle. It also has evenly spaced slits along its circumference. Collets are typically purchased in sets that will cover a broad range of tooling shank diameters. One collet will fit a few different sized shanks.
- **Center**. Centers are precision ground cones used to center and support workpieces. The center typically features a 60° taper that comes to a point. Centers are used to "center" tubular workpieces, such as barrels, but will also support rods or other workpieces that have a pilot center drilled.
- **Mandrel**. A mandrel is used to hold hollow objects that may not fit in a chuck or spindle. It features a shank that fits into the chuck or spindle, followed by a shoulder or washer to stop the workpiece against. The workpiece slides over the center of the mandrel and is capped by

another washer and finally a nut to clamp it down. The mandrel will allow you to turn a very small (length) workpiece or ones with an irregular shape.

- **Dog**. A dog is a device that clamps over a workpiece and is used to transfer power from the spindle into the workpiece. It is used when you are turning between centers (both the head and tailstock are using centers) and there is not enough energy being transferred to the workpiece. The dog features a ring-shaped body for the workpiece to pass through. It uses a locking screw to clamp down against the workpiece and a tail that fits inside a hole in the drive plate. The dog relies completely on the drive plate for its power.
- **Drive/Face Plate**. The drive/face plate is used to drive the dog and workpiece. It features a series of slots and holes used to hold the dog or to provide mounting space for clamps to hold irregularly shaped workpieces. A drive plate is usually required when turning between centers.
- **Steady Rest**. A steady rest is a device used to support long workpieces or workpieces that may flex under heavy cutting. It can be positioned anywhere along the bed affixed to the ways. The rest uses a series of adjustable fingers arranged around the circumference of the workpiece. The fingers are all adjusted until they touch off on a centered workpiece. The ends of the fingers may also feature roller bearings for smooth rotation.
- **Thread Pitch Gauge**. The thread pitch gauge is a tool used to measure different thread pitches. The gauge(s) features many small teeth along one edge that match the size, shape, and pitch of a specific thread. A gauge set will include gauges for the most popular thread pitches.

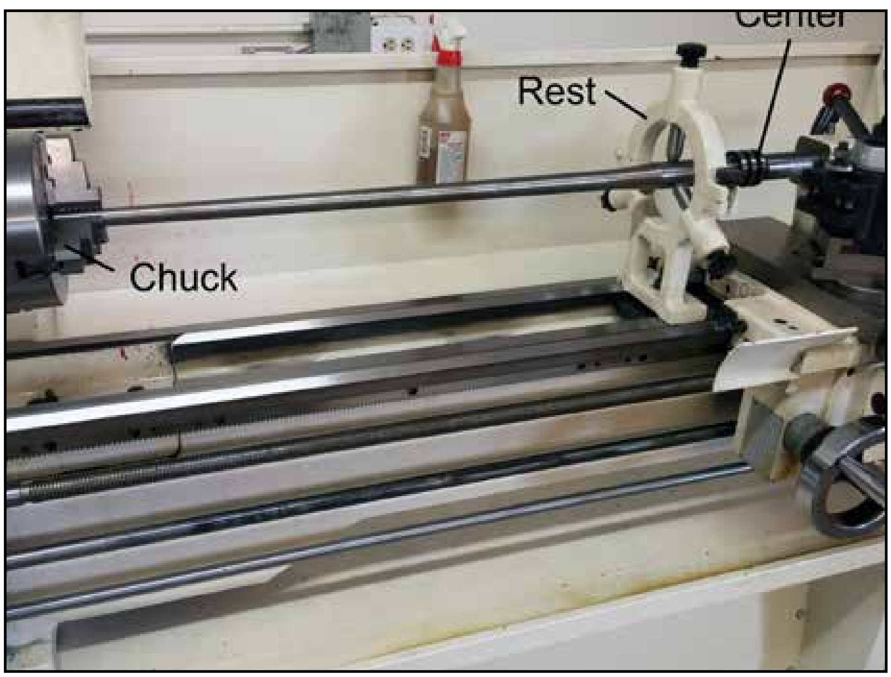

***Figure 10**: A 3-jaw chuck, steady rest, and center setup.*

- **Center Gauge**. A center gauge is a tool used to center thread cutters on a lathe. It features a series of notches that are matched to a specific thread profile (typically 60°). The center gauge is placed against the workpiece and the cutter is aligned with the notches on the sides on the gauge. The center gauge is also known as a fishtail gauge.

MAINTENANCE

Like any other heavy duty machine, the lathe requires periodic maintenance to prolong the machine's life and preserve its precision. Each specific machine will have its own maintenance regimen. Regular maintenance will guarantee a long service life for your machine. Table 2 is a general checklist of things to check based on machine usage. It is a general maintenance guide; refer to your owner's manual for specific guidelines for your machine.

GENERAL SPEEDS AND FEEDS

Using the correct cutting speeds and feeds while machining will ensure a clean, smooth workpiece. Speeds and feeds will vary with the type of machine, tooling, and composition of the workpiece. Below is a chart with general cutting speeds and feeds. These figures will provide a starting point, but you will need to use your own discretion and experience.

Cutting speed (CS) of a material is the optimal number of feet per minute the tool/bit should move through the workpiece. The optimal speed is based on the assumption the tool/bit is sharp and the appropriate lube is being used. Cutting speed is also much slower (⅓ to ¼ cutting speed) for operations such as threading, knurling, and cut-off.

Feed rate refers to how fast the tooling/bit moves through the material being cut. Feed rate for a mill is calculated using feed per tooth to give you inches per minute. Feed rate for the lathe is calculated using feed per revolution.

Maintenance Chart	
Every 8 hours of operation	Check cleanliness of ways and remove any debris. Check way lubrication. Check oil reservoir level.
Every 40 hours of operation	Thoroughly clean the machine of any chips, swarf, oil, coolant. Check oil and coolant reservoir (if applicable).
Every 160 hours of operation	Clean oil filter. Check electronics (contacts, switches, and connections) for dirt, oil, and water. Clean and tighten connector, if necessary. Check or fill oil and grease fittings.
Every 1000 hours of operation	Change oil or coolant. Check or replace drive belts or gears. Inspect bearing runout. Clean or replace way wipes.

***Table 2**: Suggested maintenance frequency for a lathe.*

Approximate Material Cutting Speed and Lathe Feed per Revolution[6]				
Material	**Mill Cutting Speed HSS**	**Mill Cutting Speed Carbide**	**Lathe Feed per Revolution HSS**	**Lathe Feed per Revolution Carbide**
Low Carbon Steel	80 – 120	300 – 400	.002” – .020”	.006” – .035”
High Carbon Steel	60 – 100	200	.002” – .015”	.006” – .030”
Stainless Steel	100 – 120	240 – 300	.002" – .005”	.003” – .006”
Aluminum	400 – 700	800 – 1000	.003” – .030”	.008” – .045”
Brass/Bronze	110 – 300	600 – 1000	.003” – .025”	.008” – .040”
Plastic	200 – 500	1000	.005” – .050”	.005” – .050"

Approximate Feed Rates (Feed Per Tooth) of End Mills[6]					
Material	**.050” Depth of Cut**			**.250” Depth of Cut**	
	⅛	⅜	½	⅜	¾
Low Carbon Steel	.0005” – .001”	.002” – .003”	.003” – .004”	.001” – .002”	.002” – .004”
High Carbon Steel	.0003” – .001”	.001” – .003”	.002” – .004”	.0003” – .001”	.001” – .004”
Tool Steel	.0005” – .001”	.001” – .003”	.002” – .004”	.001” – .002”	.003” – .004”
Cast Aluminum Alloy	.002”	.003”	.005”	.003”	.008”
Hard Cast Aluminum	.001”	.003”	.005”	.003”	.006”
Brass/Bronze	.0005” – .001”	.003” – .004”	.004” – .006”	.002” – .003”	.004” – .006”
Plastic	.002”	.004”	.005”	.003”	.008”

Approximate Twist Drill Feeds (Feed Per Revolution)[6]			
Drill Size Inches	**Drill Feed Inched**	**Drill Size Metric**	**Drill Feed Millimeters**
⅛” and smaller	.001” – .002”	3 mm and smaller	.02 mm – .05 mm
⅛” to ¼”	.002” – .004”	3 mm to 6 mm	.05 mm – .10 mm
¼” to ½”	.004” – .007”	6 mm to 13 mm	.05 mm – .10 mm
½” to 1”	.007” – .015”	13 mm to 25 mm	.18 mm – .38 mm
1” to 1½”	.015” – .025”	25 mm to 33 mm	.38 mm – .63 mm

[6] *Please note that all speeds and feeds are approximations. Actual speeds and feeds may vary with specific alloy, setup, and operation. Refer back to a machinists' handbook or other reference material.*

Quick RPM/Spindle Rate Calculations for Drill, Mill, and Lathe (HSS Cutters)[6]					
Material	**¼" Diameter**	**½" Diameter**	**1" Diameter**	**1½" Diameter**	**2" Diameter**
Low Carbon Steel	1600 RPM	800 RPM	400 RPM	267 RPM	200 RPM
High Carbon Steel	960 RPM	480 RPM	240 RPM	160 RPM	120 RPM
Aluminum	4000 RPM	2000 RPM	1000 RPM	667 RPM	500 RPM
Brass/ Bronze	320 RPM	1600 RPM	800 RPM	533 RPM	400 RPM

Revolutions per minute (rpm) is the turning speed of the tooling/workpiece. By using cutting speed and tool diameter you can calculate rpm.

CALCULATING RPM FOR DRILLS, MILLS AND LATHES

RPM = (CS x 4)/Diameter

RPM – spindle speed or speed of the workpiece

CS – material cutting speed

Diameter – diameter of the bit/workpiece

Example: Calculating spindle rpm for turning a ¾ in. high carbon steel rod on a lathe. The recommended cutting speed for high carbon steel is 60 – 100, so we'll use 80.

RPM = (80 x 4) /.75

RPM = 320 /.75

RPM = ~426

You will want to round down to your machine's next available setting.

Example: Calculating spindle speed for milling a piece of aluminum with a carbide 1 in. end mill. The recommended cutting speed for aluminum is 800 – 1000, so we'll use 800.

RPM = (800 x 4)/1

RPM = 3200/1

RPM = 3200

CALCULATING FEED RATE FOR DRILLS AND MILLS

The feed rate in inches per minute is calculated using the number of cutting teeth, rpm, and feed per tooth.

Feed Rate = (Number of Cutting Teeth x RPM x Feed Per Tooth)

Example: A ½ in. end mill with 4 flutes, spinning at 500 rpm, with a feed per tooth of .004 in., at .050 in. depth will have an approximate feed rate of:

Feed Rate = (4 x 500 x .005 in.)

Feed Rate = 10 inches per minute

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Introduction to Barreling, Chambering, and Rechambering

The ability to barrel (or rebarrel) and chamber (or rechamber) is an extremely valuable skill to learn for anyone interested in becoming a gunsmith. The ability to barrel a gun is beyond the ability of an armorer or the common hobbyist gunsmith. Turning (literally) a rifled blank into a finished barrel requires the use of a lathe. Finishing a short-chambered barrel can often be accomplished with specialty hand tools. Regardless of the starting point (blank or short chamber), you will have to ensure that it is installed safely and correctly and that it performs as expected. Before you can jump right into it, there are a few things you will need and a few things you will need to consider.

TOOLS AND MATERIALS

Depending on whether you are barreling a new rifle or rebarreling or rechambering a used one, there are some machines, tools, and materials you will need to complete the job safely and correctly.

This is a list of the most basic tools needed to properly turn a barrel and chamber it.

- **Lathe and Tooling**. A lathe is an invaluable tool when considering barreling. Every process required for turning and chambering a barrel can be performed on a lathe. With the help of a 3- or 4-jaw chuck, dial indicator, turning, facing, and thread cutters, you can transform a rifled blank into a functioning barrel.
- **Chamber Reamer**. A chamber reamer is a special profile cutter. The profile of the cutter is dimensionally proportional to the cartridge it represents. The reamer is used to cut the throat and body (neck, shoulder, belt and rim, if applicable). Depending on the type of reamer,

***Figure 11**: Cutting a chamber.*

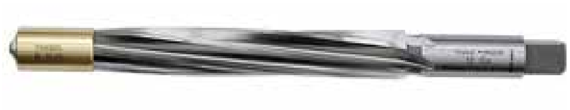

Figure 12: Chamber reamer.

typically there is a pilot on one end that holds the cutter centered on the bore. The other end of the cutter is shaped so it can be mounted in a chuck, collet, or other tool holder.

- **Chamber Reamer Holder**. Chamber reamer tool holders are used to hold the reamer in the lathe while cutting. There are many different ways to hold the reamer from chucks and collets to specialty "floating" holders. For inexperienced users, a "T" handle with a center machined into it will be the best choice. It will allow you to "feel" the cut and compensate for chatter.

- **Receiver Tap**. A receiver tap is used to cut and clean the receiver threads. Receiver taps are typically model-specific as most companies use different thread pitches.

- **Barrel and Action Wrench**. Barrel and action wrenches are used to install and remove the barrels from the action. Typically, the action wrench is specific to the type of action, while the barrel wrench may be universal with the help of inserts. The barrel may need to be torqued onto the action as high as 80 – 100 lb-ft. The barrel and action wrenches are invaluable when it comes to installing barrels.

- **Bolt Lapping Fixture**. The bolt lapping fixture is used to lap the bolt lugs to the receiver lugs. Lapping the lugs ensures there is enough contact between the bolt lugs and receiver lugs to properly support the chamber pressure. The lapping fixture is spring-loaded and threads into the front of the receiver. The spring-loaded plunger pushes back against the bolt face, causing the lugs to rub against each other. Lapping compound is used to wear the lugs into each other until the required amount of contact is reached. The lugs require at least 80% contact to ensure proper function. If the lugs are not in contact when the round is discharged, there is a great chance that bolt thrust will shear the lugs and send the bolt out the rear of the receiver.

- **Headspace Gauges**. Headspace gauges are precision instruments used to gauge the size of the chamber. The headspace gauge is dimensionally proportional to the cartridge it represents. There are three types of headspace gauge. The *Go* gauge represents the absolute minimum chamber size needed to fully chamber a barrel. The *Field* gauge represents the absolute maximum chamber size required for a safe chamber. The *No-Go* gauge represents a chamber that is longer than needed but not completely out of spec.

Figure 13: Headspace gauges.

With a perfectly cut and spec'd chamber, the bolt should lock a Go gauge in the chamber with little to no resistance. The bolt should not close on a No-Go or Field gauge. If the bolt closes on a No-Go gauge, it is not useless. However, it will have diminishing accuracy and experience malfunctions. If the bolt closes on a Field gauge, the gun is deemed out of spec and unsafe and must be repaired.

- **Thread Pitch Gauge**. The thread pitch gauge is a tool used to measure different thread pitches. The gauge(s) feature many small teeth along one edge that match the size, shape, and pitch of a specific thread. A gauge set will include gauges for the most popular thread pitches. The thread pitch gauge may also show thread angle, which is very useful because all threads are not 60°.

- **Deburring Tool**. A deburring tool is used to remove small slivers of metal left over from most machining processes. The deburring tool features a small curved cutter that rotates in its body. The deburring tool is typically used to deburr and slightly chamber holes but can also be used to deburr the outside of parts.

- **Chamber Polishing Tool**. The chamber polishing tool is used to smooth the chamber after cutting. Although there are specialty chamber polishing tools like the Flex-Hone®, you can use a wooden rod with a slit in one end to accept sandpaper.

- **400-Grit Sandpaper**. Sandpaper is used to polish the chamber. The sandpaper is wrapped around a wooden mandrel and placed inside the chamber while the lathe is spinning, removing any chatter or roughness the reamer left behind.

Figure 14: Chamber polishing mandrel.

- **Metal Saw**. The metal saw is used to cut the barrel blank to a more manageable size. Cutting the barrel by hand with a metal saw is the preferred method because it will not overheat the barrel blank and ruin the temper.

- **Machining Fluid**. Machining fluid is used to keep the cutter cool and help chips flow away from the chamber.

- **Chamber Brush**. The chamber brush is used to clean the chamber of chips between cuts.

- **Cleaning Patches**. Cleaning patches are used to clean the chamber of any oil and leftover chips. To use a headspace gauge to check the chamber, it must be clean and free of oil, chips, or other contamination that may give a false reading.

- **Small Flashlight**. A small flashlight will help you to see the inside of the chamber while it is set up in the lathe. A small flashlight with 25 – 50 lumens will be enough light to see the work.

Figure 15: Other materials.

- **Small Brush**. A small brush is used to clean the reamer between cuts. You want to keep the reamer and the chamber as clean as possible while cutting to prevent galling and scratches from chips wedging between the cutter and chamber.

Some optional tools are available to help "blueprint" the bolt and action. These tools are not necessary but will help to produce a more accurate and precise rifle overall.

- **Bolt Face Truing Fixture**. The bolt face truing fixture is used to align and hold the bolt in a lathe so that its face and lugs can be cut true and perpendicular to the bore's axis. Truing the fit and alignment of the bolt, receiver, and barrel will guarantee the greatest overall precision and performance.
- **Action Truing Fixture**. The action truing fixture is used to align and hold the receiver in a lathe so that its shoulder, threads, and lugs can be cut true and perpendicular to the bore's axis.

BARRELING

Properly barreling a rifle from a blank involves a lot of planning, measuring, cutting, and fitting. This task would be nearly impossible without a lathe. To turn a rifled barrel blank into a working barrel, you need to cut, square, and thread a shank to mate to the receiver, contour the profile of the barrel, profile the breech face, and cut the chamber. All of this is only possible after you have measured and planned the length of the shank and calculated the depth of the chamber based on the depth of the bolt face and the

bolt/breech face gap. At first, this may seem like a daunting task; but with some trial and error, over time this will become a very profitable skill. You should develop a mental or physical checklist of the steps involved in barreling.

- **Preparing the Receiver**. Even if you are not going to "blueprint" the action, you will still need to prepare the receiver. Preparing the receiver includes cleaning the receiver face and cleaning and chasing the threads and lapping the bolt lugs. The receiver face is squared in the lathe with the help of a receiver truing fixture. Threads can be cleaned using a model-specific receiver tap. The bolt and receiver lugs can be lapped with minimal tools and materials. To lap the lugs, you will need a vise, marking fluid, 600-grit lapping compound, and a bolt lapping fixture. Follow the lapping fixture manufacturer's instructions to properly lap the lugs.

  If you are planning on blueprinting the action, you can use the bolt and action truing fixtures. These tools will help you to square the receiver's face, threads, and lugs as well as the bolt's face and lugs to the bore's axis to ensure the greatest overall accuracy. Refer to the fixture manufacturer's instructions for proper use.

- **Planning**. Now that the receiver is prepped, you can start to plan the barrel's dimensions and profile. There are a few things you will need to consider. What action type are you barreling? What caliber do you want to use? The type of action you use will dictate how you cut the barrel's shank, threads, breech face, and chamber. Every action type will use different specs.

  Some action types will need to cut a specific breech face profile, whether it is flat, coned, or recessed (counterbore). Each action type will also need a specific thread profile and pitch.

  - Remington 700 actions use 1.0625 x 16 tpi (1 1/16 x 16); .885 in. shank length. Also for Remington 721, 722, 660, 600, XP-100, Model 7, 700, and 40X.
  - Mosin Nagant actions use .975 x 16 tpi.
  - Mauser large ring actions use 1.10 x 12 tpi 55° threads. 1.41 in. shank length.
  - Mauser small ring actions use .98 x 12 tpi.
  - Lee Enfield 1917 actions use 1.125 x 10 square threads; .800 in. shank.
  - Lee Enfield SMLE actions use .997 x 14 tpi.
  - Lee Enfield P 14 actions use 1.125 x 10 square threads.

Planning includes measuring the receiver and bolt and calculating the chamber depth. Drawing your parts and dimensions will help you to layout and visualize your work. You can also use chamber and cartridge drawings supplied by SAAMI as reference material. To measure the barrel shank length, you will need to measure the distance of the bolt face to the rear of the bolt lug as well as the receiver from face to the face of the front lug and current thread

length. You will have to compensate for breech face, bolt face gap, and recoil lug (if applicable). To measure chamber depth you will also need to measure the depth of the bolt recess from bolt face to the bottom of the recess and compensate for the breech gap. You can subtract this figure to known dimensions of the cartridge and its specs. The remaining figure will give you your chamber depth.

For example, let's chamber a barrel for the 5.56x45 NATO cartridge. The 5.56 cartridge is a bottleneck rifle cartridge that headspaces against the case's shoulder. From the head to the datum line (part of the shoulder the case headspaces against, roughly the middle of the shoulder) on the shoulder, the case is roughly 1.4975 in. long.

First we need to calculate the shank length. This is accomplished by measuring the distance from the receiver face to the lug face (A) and subtracting the width of the bolt lug (B) and breech gap (C). Let's say that the distance from the receiver face to the lug (A) is 1.185 in. and the bolt lug (B) is .280 in. wide and the required breech gap is .005 in. (C) (breech gap may be as small as .003 in. but may cause issues when the chamber is dirty). Using these figures we can calculate the shank length.

Shank length = 1.185 in. - .280 in. - .005 in.

Shank length = .900 in.

This means we will need our shank to be .900 in. for everything to function properly (assuming we do not have to compensate for a recoil lug. If a lug is used, add the width of the lug to the shank length). Let's also assume the major shank diameter is 1.0625 in. (1¹⁄₁₆) with 16 tpi thread pitch (with a minor thread diameter of .9880 in.) and the threads are .850 in. long from the shoulder with no thread relief.

Next, we will need to calculate chamber length. We know from the case head to the datum line is 1.4975 in. long. You need to measure the bolt face recess (D) and subtract it from the case length and compensate for the breech gap (C). Let's assume bolt face recess (D) is .125 in. deep. Using these figures we can calculate chamber length.

Chamber length = 1.4975 in. - .125 in. - .005 in.

Chamber length = 1.3675 in.

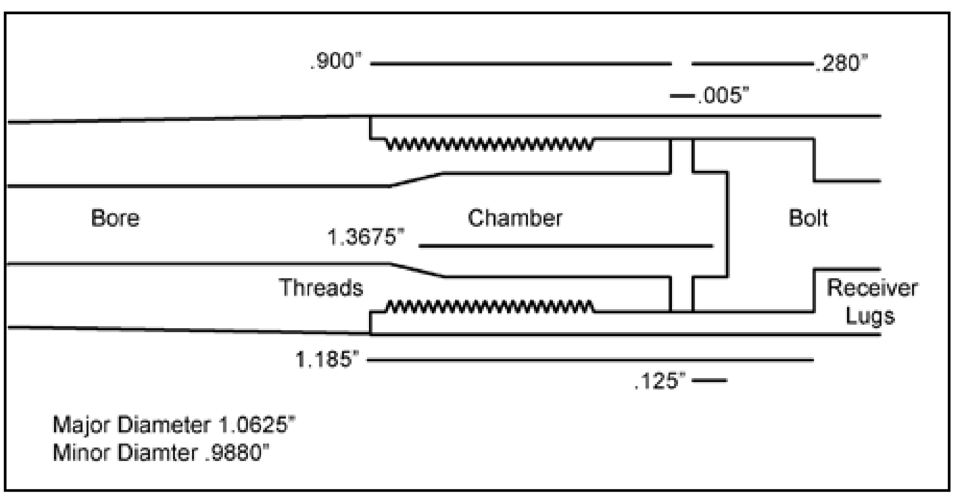

***Figure 16**: Chamber drawing.*

Figure 17: *Setting up the blank.*

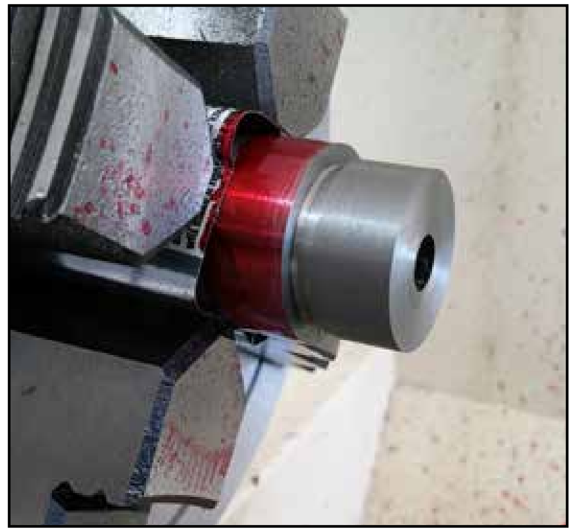

Figure 18: *Cutting the shank.*

This means we will need to cut the chamber 1.3675 in. deep to be able to close the bolt on a Go gauge. Now we have a basic drawing we can use as reference when barreling. You may also have to consider thread relief.

Other considerations include chamber wall thickness and barrel wall thickness. A good rule of thumb for high pressure cartridges like the 5.56 NATO (55,000 operating psi) is that you want the chamber walls to be at least ⅔ the width of the cartridge diameter. The 5.56 cartridge's body is .378 in. diameter. This means we want chamber wall thickness to be at least .252 in. (.378 / 3 = .126 x 2 = .252), giving us a minimum safe shank diameter of .882 in. (.252 x 2 = .504 + .378 = .882). Our major shank diameter is 1.0625 in., giving us plenty of material for extra assurance.

For barrel wall thickness you want it to be as thick as ¾ bore diameter. The 5.56 cartridge uses a .224 in. bore. This means you will need at least .168 in. (.224/4 = .056 x 3 = .0168) thick barrel walls giving you a minimum barrel diameter of .56 in. (.168 x 2 = .336 + .224 = .560), creating a pencil profile. Now that you have a drawing and plan, the rest is fairly easy.

- **Cutting the Shank**. Cutting the shank is easily accomplished once you have a plan in place. First, you will need to decide on the overall length of the barrel. Let's assume you want a 24 in. barrel. You will need to cut your blank to a minimum of 26 in. You want a little excess barrel on each end to cut back because the rifling may be scratched or damaged at the ends of the blank from manufacturing. Place the blank in a vise and use the metal hand saw to cut the blank to length. Chuck the blank into the lathe and align it (refer to "Securing and Truing")

  First you will need to face the blank. You need this face to be true because you will use it later to pull measurements from. The face also needs to be true to guarantee its alignment with the bolt face.

  Next you will need to turn the major diameter of the shank down to 1.0625 in. over .900 in. of length. If you need to cut a thread recess, now is the time. Because our threads run into our shoulder, we do not need a thread recess.

Once the shank it profiled to spec, you can begin cutting threads. Threads should be cut so that the barrel's shoulder will thread all the way to the receiver's face with little to no resistance. (Refer to "Turning" section for instructions on threading.) Once the threads are cut, you will need to cut a small chamfer on the shank.

- **Cutting Bolt Recess**. Depending on the type of action you are barreling, you may need to cut a bolt nose recess. Some actions use a conical recess while others use a counterbore recess. Whichever recess type you require, make certain you have at least .005 in. breech face clearance.
- **Turning the Contour**. The contour or profile is going to be a matter of personal preference. Every long-range and precision shooter has his or her own idea of the best profile for ultimate precision. Sometimes, the type of action used or the stock will dictate the barrel's profile (unless a lot of modification is planned). The barrel's profile comes from a series of diameters, steps, tapers, and shoulders. Profiles can be broken down into four major profiles: bull, target, standard/sporter, and light/featherweight.

***Figure 19**: Threading the shank.*

Bull refers to a barrel that features a 1 in. or larger diameter along most of its length. The advantage of bull barrels is that they are extremely stiff. Precision is directly related to barrel stiffness. Bull barrels will require more shots to be fired before reaching high temperatures, but will also retain heat longer. Bull barrels are also very heavy. Sometimes, the barrels are fluted to help offset some weight while retaining stiffness.

Target refers to a barrel that may start at 1 in. in diameter, and then tapers the entire length of the barrel down to around .750 in. Target barrels tend to be fairly stiff but not as much as bull barrels. Target barrels are not nearly as heavy as bull barrels, either, and will dissipate heat faster. They also tend to heat up faster.

Standard refers to a barrel that starts out at around 1 in. for about 3 in. and then steps down with a shallow shoulder to around .800 in. and tapers the rest of the way to around .700 in. Standard profile barrels are one of the most common profiles because of their greater overall performance. The standard profile barrel retains a lot of rigidity while being light enough to carry over long periods of time (like hunting). For most applications, the standard profile will outperform the person behind the trigger.

Light refers to a barrel that starts off less than 1 in. (around .950 in.) for about 2 in., then steps down with a steep shoulder to around .700 in. and tapers the length of the barrel to around .650 in. Light profile barrels are the least stiff and heat up fast. The main advantages of light barrels are the weight and the fast heat dissipation.

There are many other profiles available, but most are just a variation of the above. Be aware that you may have to

turn a barrel to fit band-style sights, gas blocks, mounts or lugs, or to create clearance for other parts. You may also be able to purchase blanks that have been pre-profiled. Once the profile is done, you can begin chambering.

CHAMBERING

Chambering is one of the simplest and most critical parts of barreling an action. If done correctly, the rifle will function, hopefully with great degree of precision. If done incorrectly, the rifle will not group well and may even be extremely dangerous. It is extremely important that you go slow, keep the reamer and chamber clean, and measure often.

SHORT VS. LONG CHAMBERING

At this stage you have a blank that has a threaded shank and is profiled. To save time you could start with a short chambered barrel. A short chambered barrel will come with the shank precut and a chamber cut to within about .010 in. of final length. The short chambered barrel is complete to the point you can finish one by hand. With the help of a chamber or finish reamer and a T-handle, you can cut the chamber the remaining length. Since we already have a partially finished blank setup in the lathe, let's discuss long chambering.

To cut a full-length chamber, all you will need is the reamer, a T-handle holder with a center, a center in the tailstock, headspace gauges, and a depth micrometer. To start, you will need to secure the reamer in the T-handle and then place a well-lubricated reamer in a lubricated bore. The pilot should be tight enough that the reamer does not wobble, but not so tight that it causes binding. Move the tailstock over until the center engages the dimple on the T-handle. Use the handwheel to move the spindle out until the dial moves back around to zero. Lock the tailstock in place and back the spindle out about .010 in. With one hand holding the T-handle loosely, turn the machine on. Move the spindle back to zero. While holding the reamer handle, use the handwheel to push the reamer into the bore. Advance slowly and let the feel of the handle dictate your feed speed. If you feel a lot of force on the handle, slow your advance; if you don't feel any force, accelerate your feed. Your first passes should be fairly deep, cutting around .100 in. before backing out and cleaning.

While still holding the handle, disengage the clutch. When the machine stops spinning, back the spindle and tailstock out and remove the reamer. Use a brush to remove any chips from the reamer and chamber and relube. Place the reamer back in the bore and set the tailstock back in place. We are cutting the chamber 1.3675 in. deep, so you will need to make at least 13 passes, 100 in. deep to bring it to 1.300 in. The next six passes should be .010 in. deep, bringing it to 1.360 in. Once you remove the reamer and clean the bore, check the depth of the chamber with a Go gauge.

Clean the chamber thoroughly for any chips, oil, or other debris. Use a cleaning patch to wipe the chamber of any leftover oil. Place the headspace gauge in the chamber. The head should be poking out of the chamber. Measure the gauge's protrusion from the breech face. The protrusion should be equal to the depth of the bolt face and the breech gap plus .007 in. (what we should be short). Based on a bolt face depth of .125 in. and a breech gap of .005 in. plus .007 in., the gauge should be protruding .137 in., leaving .007 in. to cut.

***Figure 20**: Cutting the chamber.*

At this point you will want to screw the action onto the receiver and try to close the bolt on a Go gauge. If all of your planning and cutting have been correct, the bolt should not close. Remove the action and gauge and set the reamer and tailstock up to cut again. Your next seven passes should be made a .001 in. deep each, bringing us to 1.3670 in. After each pass you should thoroughly clean the chamber and check if the bolt will close. If you reach 1.3660 in. and the bolt closes, you are done. The chamber is cut to full length. Remove the reamer and clean out the chamber.

Once the chamber is cut to full length, you will need to polish it. Using your polishing dowel and 400-grit sandpaper, lightly polish the chamber. With the machine running, place the dowel in the chamber and apply light pressure. Use a small flashlight to check the chamber. You want to polish the chamber to the point all tool marks are gone, but not so much you open up the dimensions of the chamber. While you have the polishing dowel out, you can radius the mouth of the chamber and breech recess (if applicable). You may also have to cut a notch in the breech face for extractor clearance.

Once the breech end of the barrel is complete, you can turn it around in the lathe and finish the muzzle end. Follow the setup procedures explained under the section "Securing and Truing." You need to decide what type of muzzle profile you want. You can either cut the muzzle square and then crown it, or you can thread it for a flash hider/brake/compensator. Whichever style you choose, you will need to cut the barrel to final length. Remember that barrel length includes the chamber and is measured from the breech face to the end of the muzzle. A minimum of 16 in. barrel length is required before you have to register as an SBR. Once the length is cut and the muzzle is finished, you will have a complete barrel ready to torque onto the action.

RECHAMBERING

You may also be able to rechamber an existing barrel. The reason you would rechamber a barrel is because the current chamber is damaged or worn or you want to change calibers. There are a lot of factors to consider when rechambering a barrel. First, if the chamber is damaged or worn, how much of the chamber is damaged/worn? Is there enough material on the barrel to turn a new shank or extend the current one? Is the barrel's OAL long enough to cut a fresh chamber?

If you are rechambering the barrel for a different caliber, there are even more factors to consider. When rechambering to a new cartridge, you are restricted to similar calibers. For example, if you have a barrel chambered in .308 Winchester, you are limited to .30 (.308). This means you can rechamber for larger .30 caliber cartridges like the 30-06 or the 300 Win Mag, but you can't rechamber for a shorter cartridge like the 300 Blackout. You will also have to consider if the new cartridge will fit in the action or the magazine. Will the new round fit in the bolt face? Is the profile of the barrel long enough to provide adequate chamber wall thickness? Once you have made a decision, the planning process for rechambering is the same as chambering. The only change is going to be the chamber length. The machining process also mirrors chambering.

NOTES

Chapter 5 - Rebarreling and Headspacing

Introduction

The installation or alteration of a barrel is a common job in the gunsmithing profession. Such a job requires the ability to work with a lathe and the technical knowledge of various procedures and operations.

There are many reasons for rebarreling a rifle. For instance, the original barrel might have been shot out or become pitted due to misuse or neglect. The shooter might have a new barrel that needs to be chambered for a special "wild-cat" cartridge. An existing barrel might need to be rechambered for an improved cartridge.

The shooter might have acquired a rifle action — such as a Springfield® or Mauser—and would like to build a custom rifle from scratch. Whatever the reason, rebarreling a rifle is a common request for many gunsmiths. Because of this, it is important for you to become associated with barrel work. Even if you do not intend to do the work yourself, knowledge of the procedures can help you discuss the matter more intelligently with your customers or the person doing the work for you.

This lesson gives you an overview of turning and contouring barrel blanks to the desired dimensions, how to thread the barrel for attachment to the rifle receiver, and how to chamber the barrel for a specific cartridge.

Lathe Lore

The screw-cutting, metal turning lathe is the oldest and most important machine tool. From it practically all other machine tools have been developed. Lathes vary in size from the jeweler's or clockmaker's lathes used for making tiny parts to the large gap bed lathes and special-purpose lathes used in mass production work.

The lathe size is determined by the diameter and length of the work the lathe can handle. For example, a 9 in. x 36 in. lathe has a swing over the bed that is large enough to handle work up to 9 in. in diameter and a distance between lathe centers of 36 in.

When selecting a lathe for gunsmithing work, consider the needed size and amount of work required by the lathe. Ideally, the lathe selected should have a swing capacity and distance between centers at least 10% greater than the largest anticipated job.

PARTS OF A LATHE

A lathe, shown in Figure 1, is made up of many parts. The principal parts include the bed, headstock tailstock, carriage, feed mechanism, and thread-cutting mechanism.

Bed. The bed is the foundation on which the lathe is built. It must be well-constructed and designed. The most common types of beds are flat-ways and prismatic V-ways. Flat-ways are shown in Figure 1.

Headstock. The headstock is on the left-hand end of the bed and is one of the most important parts of the lathe. It should be geared toward the back to allow more versatility. The back gear provides a means of controlling the spindle speed. A lever engages the back gear for slow spindle speeds (75-280 revolutions per minute (rpm)) or disengages it for high spindle speeds (300-1,100 rpm).

Tailstock. The tailstock assembly moves on the bed ways and carries the tailstock spindle. The tailstock spindle has a standard Morse taper to receive various types of lathe centers. The

This 30-06 Springfield rifle manufactured by the firm of Ernest Dumoulin in Herstal, Belgium features a tapered octagon barrel with a hooded ramped beaded blade front and two-leaf (one standing, one folding) rear notch sights.

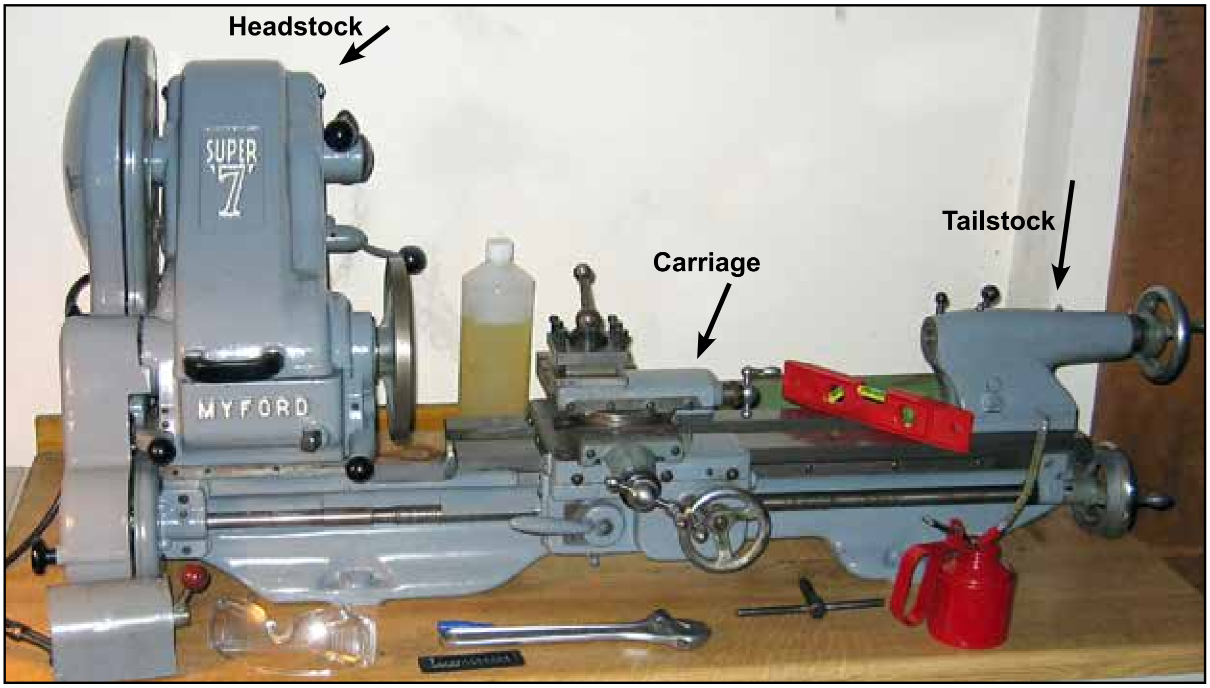

Figure 1: *The Myford Super 7 is a high-quality lathe, ideal for a gunsmith's first lathe.*

tailstock handwheel is at the other end to give longitudinal movement when the workpiece is mounted between centers. The tailstock can also be used for drilling operations when the work is held in a gripping device, known as a chuck, or bolted on the faceplate so the work revolves and the drill remains stationary.

Carriage. The lathe carriage includes the apron, saddle, compound rest, and tool post. Since the carriage supports the cutting tool and controls its action, it is one of the most important units of the lathe.

Feed Mechanism. Quick-change gear lathes are preferred in gunsmithing shops where frequent changes of threads and feeds are required. On most lathes, the quick-change gearbox is located directly below the headstock on the front of the lathe bed. A wide range of feeds and threads per inch can be selected by positioning the gears. The index plate is an index to the settings of the lever, which positions the gears for the different feeds and measurements so the carriage moves per revolution of the spindle.

The reversing lever reverses the direction of rotation of the screw for chasing right- or left-hand threads and reverses the direction of the carriage assembly feed. Levers on the quick-change gearbox should never be forced into position.

CENTERING WORK

Both centers of a lathe must be in perfect alignment. One way to check center alignment is to use a test bar, such as the one shown in Figure 2. This can be a 12 in. length of round stock, 1 in. in diameter, concentric and straight to within 0.001 in. By using this type of bar, the centers can be aligned easily.

Another method used to align lathe centers is the trial cut method. The trial cut method requires that you make a tight cut on the workpiece. Measure at the tailstock end of the workpiece and at a point midway between centers. If there is a difference in the two readings, then the tailstock is moved to the measurement that equals the difference. If the tailstock end is the

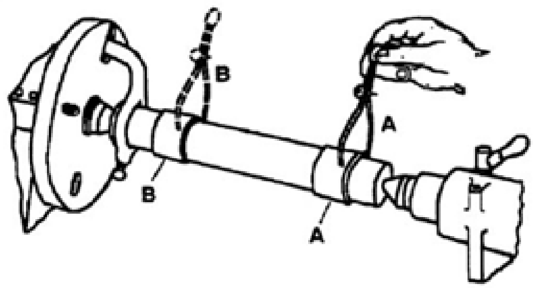

Figure 2: *A test bar being used to check lathe centers. A test bar must be concentric and straight to within 0.001 in.*

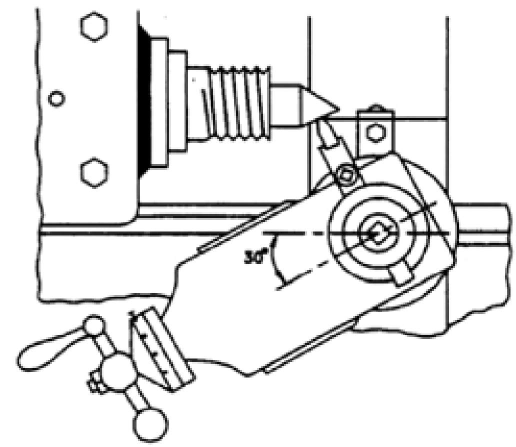

Figure 3: *The degree setting on a compound rest for turning 60° lathe centers.*

larger of the measurements, the tailstock is moved toward the operator; if the tailstock end is smaller, it is moved away from the operator.

TAPER-TURNING

One of the operations that often confronts the professional gunsmith is tapering a rifle barrel from a barrel blank. In general, there are at least three methods for taper-turning on a metal-cutting lathe. The simplest method is performed by swiveling the compound rest to the required angle and traversing the top slide by hand. Naturally, this method is limited to short taper parts, such as lathe centers, to hold the barrel blank because the top slide is limited to only a few inches of travel (Figure 3).

TOOL SETTING

When conventional cylindrical work is being turned, the height of the cutting tool has little effect on the accuracy of the work, although it might affect the quality of the finish. However, when tapering centers on a lathe, the cutting tool must be exactly on the centerline of the work, as illustrated in Figure 4. Otherwise, a true cone cannot be obtained.

In Figure 4, the full lines represent the small and large ends of a taper surface. The cutting tool moves outward the distance A as it travels along the workpiece. However, if the tool is set at the height B, where the tool would touch the small end of the taper, and then traversed along, the tool would still move distance A. In this case, the tool would terminate at the dotted line position, making the large end of the taper much too small. When turning the work to a fine point, such as the lathe center, if the tool is set either above or below the work center, the tool leaves the work before a point can be produced. It is impossible to produce a pointed workpiece unless the tool is set correctly.

A simple way to set the tool correctly is to compare the height of the cutting edge with one of the lathe centers before placing the work in the lathe.

OFFSETTING TAILSTOCK

One of the most popular methods of tapering long workpieces is offsetting the tailstock, as shown in Figure 5. When the tailstock is offset, the angle of the taper varies according to the length of the work. The amount of offset depends on the amount of taper per foot and the overall length of the work. With the same amount of offset, pieces of different lengths can be machined with different tapers.

Setting the tail stock toward the operator (or tool post) results in a taper with a smaller diameter at the tailstock; setting the tailstock in the opposite direction results in a smaller diameter at the headstock.

To determine the proper amount of tailstock offset, remember that the tailstock center is offset one-half the total amount of the taper for the entire length of the work. Following are equations to be used to calculate the amount of offset.

When the taper per foot is given, such as inches per foot, the equation used is:

$$\text{Offset} = \frac{\text{taper per foot} \times \text{length of taper in inches}}{24}$$

To demonstrate the use of this equation, assume that a piece of stock is exactly 1 ft. long and is to be tapered ½ in. per foot. Substituting these values in the equation, we have:

$$\text{Offset} = \frac{.5 \times 12}{24} = 0.250 \text{ or } ¼"$$

To obtain the required taper, the tailstock should therefore be set ¼ in. off center. If the piece were only 10 in. long, then the offset would be:

$$\text{Offset} = \frac{.5 \times 10}{24} = 0.208"$$

When the entire length of the piece is to be tapered and the diameters at both ends of the tapers are known, divide the large diameter minus the small diameter by 2 to obtain the amount of offset. For example, a piece of stock 1 ft. long with a 1 in. diameter at one end and ½ in. diameter at the other, should have the tail stock set over the following amount:

$$\text{Offset} = \frac{1 - 5}{2} = 0.250 \text{ or } ¼"$$

When a portion of the stock is to be tapered and the diameter at the ends of the tapered portion are known, divide the total length of the stock

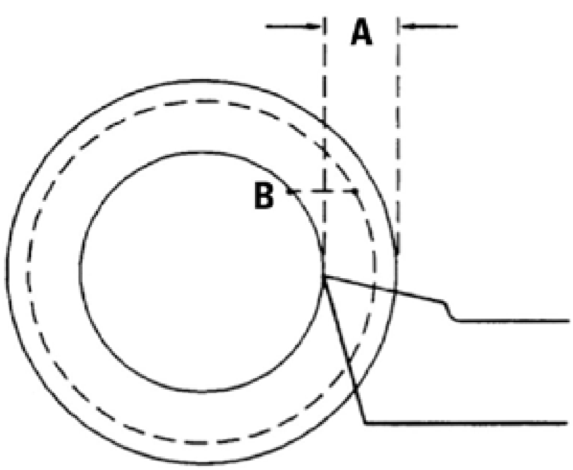

Figure 4: The cutting tool point for taper-turning must be exactly on the centerline.

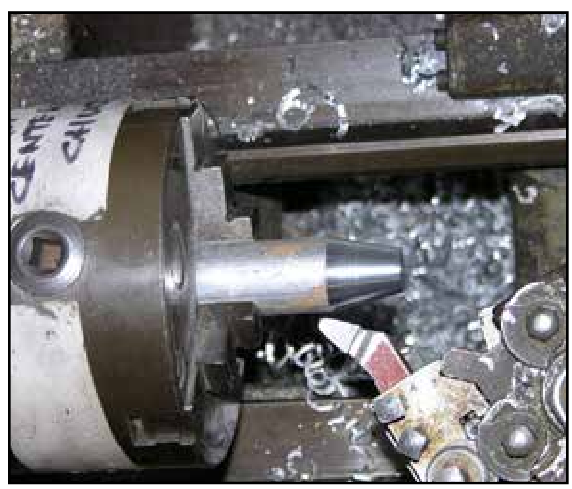

Figure 5: A tailstock showing adjusting screws.

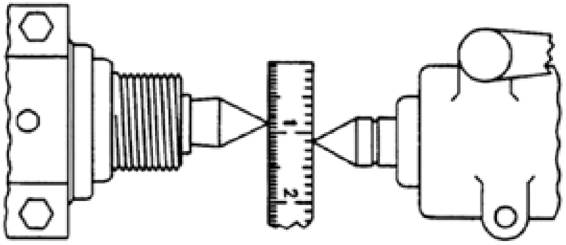

Figure 6: Approximating the amount of tailstock offset using a metal scale.

by the length of the portion to be tapered and multiply this quotient by one-half the difference in diameters. The result is the amount of offset.

Offset = total length of work
x large diameter
– small diameter

length to be tapered

2

The method of adjusting the offset will vary slightly with the make of lathe. In most cases, all that is required is to loosen the clamping nut or lever and back off one of the offset screws, located on each side of the tailstock body. Then screw in the opposite screw until it is tight and reclamp the tailstock to the lathe bed. A zero mark is usually engraved at the end to mark the normal tailstock location for parallel turning.

To measure the offset of the tailstock center, place a metal scale that is graduated on both edges between the two centers, as shown in Figure 6. This will give an approximate measurement of the tailstock offset.

The best way to machine an accurate taper is to fit the taper to a standard gauge. To test the taper, make a chalk mark along the entire length

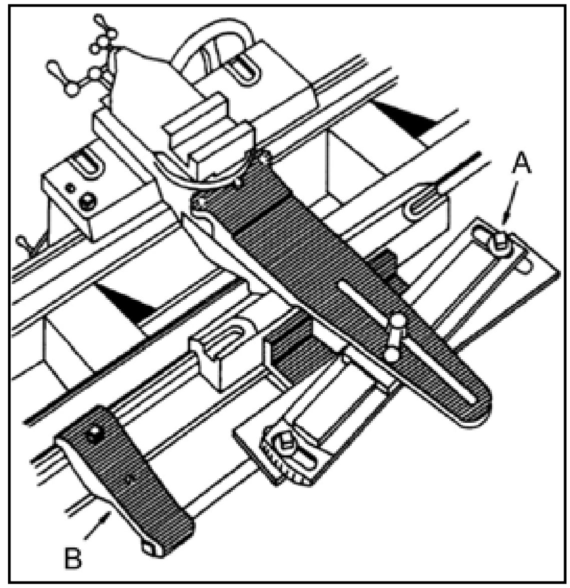

Figure 7: With a taper-turning attachment, the lathe centers remain aligned, but the tool traverses in a tapering direction according to the setting of the centers.

of the taper gauge. Then place the roughly tapered work into or onto the gauge. Revolve the work carefully by hand. Remove the work from the gauge. The chalk mark will show you where the taper is not accurate so that you can make adjustments. Be sure the taper is correct before turning to the finished diameter.

The alignment of lathe centers should be checked at regular intervals to maintain accuracy of long cuts, even though the tailstock might not have been moved purposely.

TAPER ATTACHMENTS

Many lathes are fitted with a taper attachment that permits the lathe centers to remain in alignment, as in conventional, cylindrical turning. At the same time, a taper attachment lets the tool traverse in a tapering direction as compared to the setting of the lathe centers. This

TAPER PER FT. IN INCHES	INCLUDED ANGLE	ANGLE WITH CENTERLINE
1/8	0°36°	0°18’
1/4	1°12'	0°36'
3/8	1°47'	0°54'
1/2	2°23'	1°12'
3/4	3°35'	1°12'
1	4°46'	2°23'
1 1/2	7°09'	3°35'
1 3/4	8°20'	4°10'
2	9°31'	4°46'
2 1/2	11°54'	5°57'
3	14°15'	7°08'
3 1/2	16°36'	8°18'
4	18°55'	9°28'

***Figure 8**: Conversion chart that may be used in calculating measurements for taper-turning.*

arrangement is considered to be the best method of taper-turning by many machinists. A typical taper-turning attachment is shown in Figure 7. It is fitted to the back of the lathe saddle and to the rear slide of the bed. A slotted bar is fixed to the tool post, and can be clamped to a short slide on swivel bar A. For plain turning, the swivel bar is aligned with the slides of the bed, so that the tool follows a longitudinal path only when the sliding feed is engaged. If the bar is swiveled, then the tool follows a path that is set by the angle of the attachment. Taper-turning attachments can be placed on any part of the bed by its clamps or screws.

To find a setting for either turning or boring, measure the end graduation, which gives the inches per foot of taper. Sometimes shop drawings and specifications are given in the terms of angles or in terms of taper per foot. The table in Figure 8 can be used to convert from one to the other.

TURNING BARREL BLANKS

Barrel blanks are normally turned to contour between centers in a lathe. Due to the custom nature of work done by many professionals, most contours turned are one-of-a-kind, and require conventional lathe-turning procedures.

This section discusses the conventional metal-turning lathe.

Begin by cutting the raw length blank approximately ¼ - ⅜ in. longer than the finished length, allowing for any metal that will have to be faced off the breech end to obtain the correct length of thread shank. At least 1 in. should always be removed from the muzzle end of a raw blank to remove any flare in the bore or grooves that might have been caused by the reamers entering or exiting during the bore-reaming process. There is always some run-out in the bore. Cutting the blank close to the finished length ensures that the bore will be concentric with the outside diameter when the blank is turned to its final length and crowned. It is best to get the length close to the finished dimension before turning, leaving just enough excess to remove any lathe center damage that might have occurred during the turning and polishing process.

A bar of heat-treated steel is used for a lathe center. This bar is first chucked in the lathe jaws and turned true. While turning, the compound rest is set at 60° with the lathe spindle revolving in reverse (Figure 9).

Once the center has been turned and is in position, check the height of the cutting edge of the lathe tool. It must be on center to obtain a true cut. Later, during the turning operation, you should check this setting again; you might have to raise the lathe tool about 0.010 in. or more above center to obtain the best cut without chatter. The height of the tool will depend upon its shape and clearance angle. Each time the center is removed from the chuck, it must be turned true again. At this point, face off the end of the barrel blank and cut it with a saw.

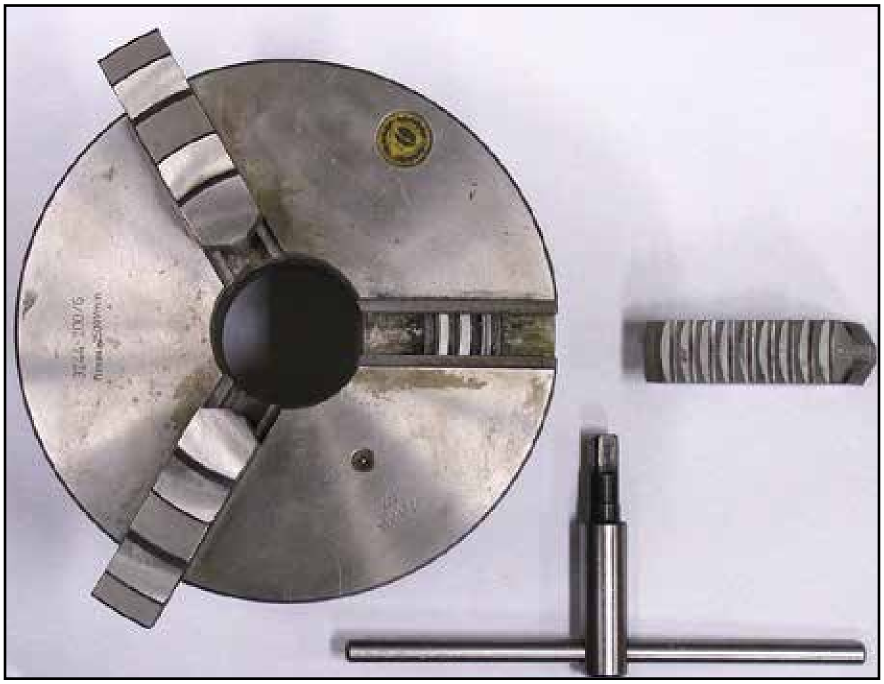

Figure 9: *Example of a 3-jaw chuck components to include the chuck key.*

During the initial turning, chatter will develop near the end of the cut. Chatter indicates that the cutting tool is digging in, causing the blank to climb up over the tool and flex away. Stop the cut and correct the situation by raising the cutting tool slightly above center.

You will find that a slightly dull tool will cut far better than a very sharp one. The type of tool used varies from shop to shop. The most popular type is the brazed carbide cutters used at speeds of 400-1,000 rpm, with a feed of 0.009-0.014 in. However, the speed and feed depends on how the part is supported—whether it is close to the chuck or the steady rest.

One method of turning is to remove the center in the chuck, and chuck up the barrel directly in the 3-jaw chuck (Figure 10). The object of the next turning operation is to remove heavy cuts at a high rpm, and with a fast feed. In doing so, the cut must be made close to the chuck, which will require moving the barrel in and out of the chuck jaws often. The blank is turned in steps during this operation, leaving enough material for final tapering later on. As the blank is reduced in diameter, shorter and shorter sections of the blank are left outside the chuck jaws. This leaves only short lengths of the blank unsupported, which reduces the likelihood of warping the blank. High speed and fast feed reduces the build-up of heat in the blank; and heat is a strong factor in causing barrel warpage.

This heavy removal of metal (hogging off) is best done in two or three stages. Chuck up the blank at one end, then turn it down, approximately 8-10 in. from the chuck. When finished, slide that portion of the blank into the chuck, and turn another section to a small diameter. Then repeat the same process. This method allows for the portion of the blank in the chuck to cool as the outside portion is being turned.

The hole through the spindle on some of the smaller lathes will not accommodate the average blank. Therefore, all turning must be done when the blank is mounted on the true center, secured in the 3-jaw chuck, and on the live center in the tailstock. During this turning operation, use

Figure 10: A barrel secured in a 4-jaw chuck. A steady rest is being used since the workpiece is long.

bore plugs in each end of the blank. Clymer™ Manufacturing Company offers them for sale at a reasonable price. When using this method, the speed and feed has to be reduced to ensure that the blank does not heat up and warp.

Once the barrel has been roughly turned on centers and stepped down, the hogged-off blank is faced-off square again. Then another true center is turned in the chuck. For the final turning, be very careful not to damage the barrel; use a fine feed and a light cut.

There are two commonly used methods for tapering rifle barrels: using a lathe taper attachment or offsetting the tailstock. The former method provides a neat, accurate cut. However, on the smaller lathes, either the barrel or attachment has to be repositioned every 8-10 in. Most gunsmiths prefer setting the tailstock to the required measurements in order to acquire the necessary taper.

In determining the proper amount of tailstock offset, remember that the amount of offset varies with the length of the barrel being turned, and that the tailstock must be reset to cut the same taper on barrels of different lengths. Be aware that setting the tailstock forward (toward the tool post) results in a taper with the smaller diameter at the tailstock end of the barrel. Setting the tailstock in the opposite direction results in a smaller diameter at the headstock end of the work.

When the tailstock has been offset by the required measurement, the barrel blank is placed in the lathe between centers. A ball bearing is then selected with an inside diameter that will fit snugly on the barrel blank at a point on either side of the blank's midway point. Rather than purchasing different size bearings for different blanks, some gunsmiths utilize one large ball

Figure 11: *A steady rest is being used on a large workpiece.*

bearing and then make an assortment of adaptor bushings for use on smaller diameter work.

With the bearing located and fitted to the blank, it is then clamped into the posts of the steady rest. An indicator is used to be sure the steady rest does not push the blank off-center of the lathe's axis. This type of arrangement supports the blank and runs extremely cool. It does not burnish a groove in the blank, as steel or bronze posts do. Bronze posts wear down rapidly and become loose, giving little support to the blank and allowing chatter to occur. Some gunsmiths use small ball bearings installed on each post of the steady rest, which results in burnishing the blank and more time spent on the process than with a single bearing.

When everything is secured in place, one end of the barrel blank is turned to final size and taper. Then the steady rest is moved, and the other section of the barrel is turned in the same manner (supported by the steady rest and bearing). Where the two sections meet, a slight blending is usually required by using a lathe file.

While there are many shortcut methods for taper-turning, the one described here ensures neat and accurate results for any type of blank. For blanks that have not been stress-relieved, this method is important and necessary since the blank can warp during turning.

Though soft steel blanks can be turned between centers without any support, barrels of harder steel must have support, like the steady rest in Figure 11.

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Cutting Barrel Threads

Threads in metal work can be produced by several different methods. The metal-turning lathe is the preferred method to use when the threads must be concentric with other turned surfaces, such as matching barrel threads to the receiver threads. Threads of various pitches can be cut on the lathe by connecting the headstock spindle of the lathe with the lead screw via a series of gears so that a positive carriage feed results and the lead screw is driven at the required speed in relation to the headstock spindle.

The lead screw on one popular lathe, for example, has eight threads per inch. The gearing between the headstock spindle and the lead screw can be arranged so that practically any desired pitch of threads can be cut. To illustrate, if the gears are arranged so that the headstock spindle revolves four times while the lead screw revolves once, the thread cut will be four times as fine as the thread on the lead screw or 4 x 8 = 32 threads per inch.

Figure 12: *A Colonial maximum bore gauge can be used in multiple calibers and without the need for a metal turning lathe.*

Either right-hand or left-hand threads can be cut by reversing the direction of rotation of the lead screw.

Threads can also be external or internal. An external thread is a thread on the outside of a member, as on a threaded gun barrel. An internal thread is a thread on the inside of a member, such as the threads on the inside of a receiver.

To cut an external thread, the thread-cutting tool is fed into the work by means of a compound rest feed. This rest is sometimes set to advance the tool squarely into the work, but many shops prefer to set the feed on a 29° or 30° angle. The cutting tool then removes metal only with its left-hand edge and tends to produce a smoother thread than if it were fed straight in. When the tool moves into the work at a 30° angle it is advanced 1.154 times the actual depth of the thread.

To prevent the tool from tearing the threads and to allow ample time to engage the dial at the proper mark, the lathe spindle speed should be slow — about 28 rpm. Once you are familiar with the size and the type of metal being threaded, the spindle can be increased. The gears, which drive the lead screw, must be arranged to produce the specified number of threads per inch.

Use a cutting oil on the work and feed the cutting tool into the work with the compound rest. When feeding in the tool, the gauge mark on the compound rest must be set for the proper depth of cut. For roughing the thread in steel, the maximum depth of cut should be not over 0.005 in., and for the last two or three cuts, no more than 0.001 in. Heavier cuts can be made on brass, bronze, and aluminum.

Once the first shallow trail cut is made, every successive cut must track in the same spiral, which requires engaging the lathe carriage to the lead screw at exactly the right moment. This is easily done with a threading dial, as shown in Figure 12. The purpose of a threading dial is to position the tool accurately in relation to the work so that

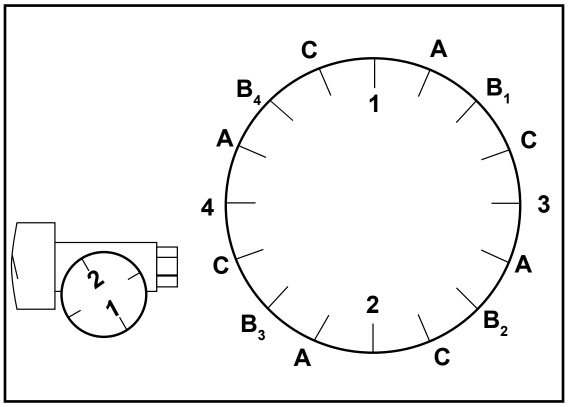

Figure 13: *A threading dial with four basic markings and additional markings for cutting multiple threads.*

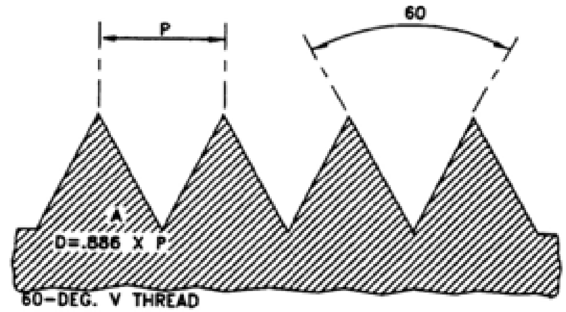

Figure 14: *A standard 60° V-thread.*

after withdrawing the tool from a completed cut the tool returns to the same starting place for the next cut. By using a threading dial, you do not need to reverse the direction of the carriage to return the tool after each cut. Standard threading dials are divided by four marks, as shown in Figure 13. If an even number of threads per inch is being cut, the lead screw can be engaged when any one of the four marks on the dial is opposite any index mark. In cutting an odd number of threads per inch, the lead screw is engaged at the same number for each succeeding cut. As the thread nears completion, it can be checked with a screw pitch gauge.

Left-hand threads are cut in the same way as right-hand threads, except that the carriage travels toward the tailstock and the compound rest is set at 29° or 30° in the opposite direction.

THREAD FORMS

In modern industry there are many different types of thread forms. Those in normal use are described below:

The *V-thread* from the American Society of Mechanical Engineers (ASME) — both fine and coarse — are practically standard for machine shop work in the United States. These threads are 60° V-threads. Other types of V-threads include the British Standard Whitworth, British Standard Fine, and British Association (B.A.). Actually, few of these are true V-threads; most of them have their points cut off so that the depth of them is 75% of the depth of a true V-thread of the same pitch.

The tool used for cutting threads is usually ground for cutting sharp-pointed V-threads. The thread is cut with the regulation V bottom, but the top is left with the proper amount of flat. Only when the utmost strength is needed should the tool be ground to the exact National Form. However, the tool can be ground to cut an exact American National Form V-thread by flattening the sharp point so that it will fit in the selected slot of the ASME gauge. The general sharp, pointed, 60° V-thread screw does work well with the corresponding nut or other internal threads (Figure 14).

ACME SCREW THREADS

The Acme screw thread is often found in power transmissions, where heavy loads require close-fitting threads. Another application is in the lead screws and the feed screws of precision machine tools. For example, the lead screw, the cross feed screw, and the compound rest feed screw of most lathes have Acme threads. Lead screws for certain types of presses and vises also use this type of thread.

Lathe threading tools are ground to the form of the thread desired. Figure 15 shows the

proper tool forms for cutting external and internal Acme threads. The forms must be checked with an Acme thread gauge during the grinding process of the bit, and also during the threading operation (Figure 16).

The various steps in cutting an Acme thread are similar to other types of threads; that is, set the compound rest at $14^1/_2°$ and advance the compound feed after each cut, returning the cross feed each time to the same setting. Threading for Acme screw threads requires a lighter cut than for conventional 60° threads because the total cutting of the tool is longer.

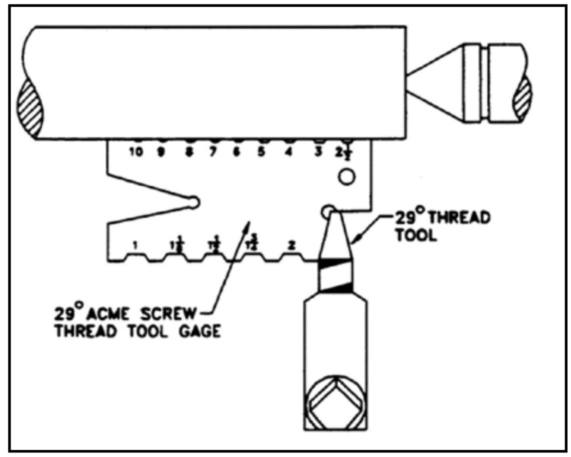

Figure 16: Checking the tool form with an Acme thread gauge.

SQUARE THREADS

The square thread (Figure 17) is seldom used anymore because it is difficult to cut. Furthermore, the resulting thread is not as strong as the Acme. Some rifle barrels, such as the 1917 Enfield and 1903 Springfield, utilized square threads for screwing the barrel into the receiver. Currently, square threads are sometimes used to rebarrel these rifles and to thread many vise and clamp screws. When the gunsmith has a choice, the Acme thread is the type recommended for all applications; it is stronger, easier to cut, and capable of closer fitting compared to the square thread.

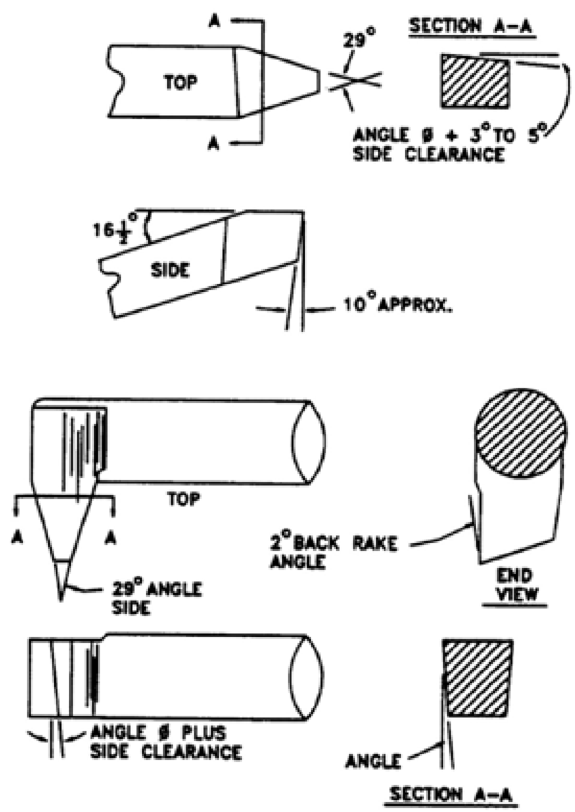

***Figure 15:** The proper tool forms for cutting external and internal Acme screw threads.*

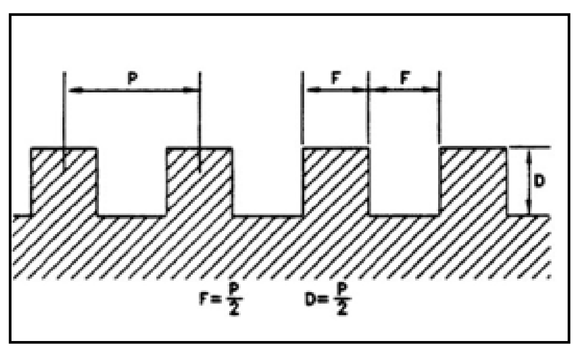

***Figure 17:** Square threads with characteristic reference marks.*

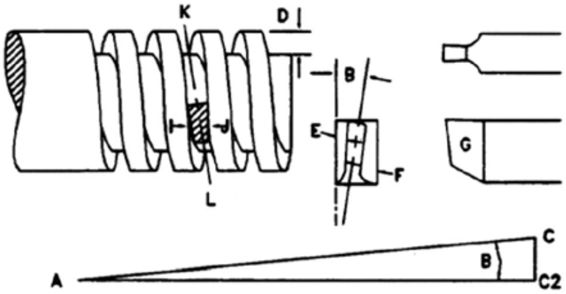

Figure 18: *Details of tools and clearances for cutting square threads.*

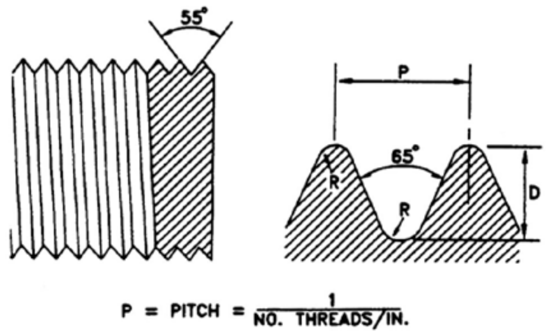

Figure 19: *Specifications of a Whitworth thread.*

In cutting a square thread with a large lead, the tool angles must be absolutely correct. Clearance should be allowed on two sides, tapering from both the top and front of the tool as shown in Figure 18.

External square threads should be cut to the minor diameter plus about 0.005 in. The additional 0.005 in. allows a small clearance at the bottom of the thread, which helps to compensate for any small inaccuracies in the tool or the cutting operation.

WHITWORTH THREADS

A cross-section of a typical Whitworth thread is shown in Figure 19. This is a standard form in Britain and Europe for many types of threads. The smaller sizes of the Whitworth form are called British Standard Fine.

A Whitworth thread is cut in much the same manner as an Acme thread except for two major differences: the thread angle is smaller, and the radius at the top and bottom of the thread must be shaped properly with a forming tool.

METRIC THREADS

The Metric Standard screw thread is now the universally accepted thread form. The metric thread angle and form are identical to that of the National Form thread, and the cutting operation is exactly the same, with one exception: the lathe motor must be reversed after each cut. This procedure is necessary because metric threads have no definite relation to the threading dial.

Metric threads, special fractional threads, and others all use the same threading method. As the tool reaches the end of each cut, back out the feed, stop the lathe, and reverse the motor until the tool has been returned to the starting position. Then advance the feed to its original 0 position, turn in the compound rest feed for the next cut, reverse the motor to the original direction, start the motor, and repeat the cutting operation.

DETERMINING BARREL THREADS

When cutting threads for rifle or handgun barrel blanks, the external threads on the barrel blank must match the internal threads of the receiver or action. The table in Figure 20 gives the average dimensions of popular rifle and handgun barrels. However, since considerable tolerance is found among rifle actions, each rifle should be treated individually. The internal threads must first be measured precisely, and then these measurements must be transferred to the barrel blank. The data in Figure 20 is accurate enough to use in determining whether or not there is sufficient stock in a barrel or barrel blank to permit fitting it to certain actions. It will also tell you whether or not your lathe is equipped to cut the required thread.

Make/Model	Thread Length	Shoulder Diameter	Thread Diameter	Type of Thread
Colt Police Positive revolver	0.725	0.570	0.445	32 TPI V
Colt Official Police revolver	0.875	0.678	0.550	32 TPI V
Colt Peacemaker single-action revolver	0.700	0.760	0.695	20 TPI V
Enfield Model 1917 rifle	0.800	1.325	1.125	10 TPI square
M1 Garand rifle	0.710	1.093	0.968	10 TPI square
Krag rifle	0.734	None	1.040	10 TPI square
Marlin Model 336 rifle	0.770	0.880	0.780	12 TPI square
Mossberg Model 80 rifle	0.900	0.810	0.725	24 TPI V
Luger pistol	0.7475	0.825	0.703	20 TPI V
Mauser '98 large ring rifle	0.625	None	1.100	12 TPI V
Ruger Blackhawk .44 Magnum revolver	0.710	0.775	0.680	24 TPI V
Springfield 1903 rifle	0.734	1.145	1.040	10 TPI square
Weatherby Mark V rifle	0.701	1.150	1.061	16 TPI V
Model 52-C rifle	1.430	0.900	0.750	20 TPI V
Winchester Model 70 rifle	0.728	1.145	1.000	16 TPI V
Winchester Model 94 rifle	1.020	0.840	0.807	20 TPI V

Figure 20: *Barrel thread data.*

Let us assume that you want to thread a barrel for a .45 Colt Peacemaker revolver. We will further assume that the barrel contour has already been turned and the chamber end of the barrel has been turned to 0.760 in. Measure off the thread length (0.700 in.) from the chamber end of the barrel toward the muzzle. The barrel blank is then inserted between centers in the lathe, and the thread-length portion of the barrel is turned to 0.695 in. — the maximum thread diameter. A fraction of an inch is also undercut at the back of the barrel shoulder. This will facilitate cutting the threads without binding.

The cutting tool in the tool post is exchanged for a V-thread cutter, the gears are adjusted for cutting 20 threads per inch, and the lathe is put on its lowest speed. Advance the cross slide until it barely touches the area on the barrel where

the threads are to be cut. Start the lathe and when the indicator on the lead screw dial indicator hits any of the four basic marks, engage the feed gear to cut a trial thread not over 0.005 in. When the cutting tool reaches the undercut, disengage the feed, back the cutting tool to its original position, watch the marks on the lead screw dial indicator, and start the feed when it reaches the same mark as it was started on before. Continue these operations until the desired thread depth is acquired. The last couple of cuts should be very shallow to obtain a clean thread. Use cutting oil generously throughout the cutting operations.

THREADLESS BARRELS

Barrels on many models of rifles use no threads at all — especially on .22 caliber rimfire rifles. Rather, a tenon is cut slightly smaller in diameter than the shoulder of the barrel. This tenon is inserted into the rifle receiver and is held in place by one or two drift pins. To fit a threadless barrel, merely turn the tenon area (from the chamber end to the shoulder) the proper diameter, file or mill the pin locking grooves into this area, and insert the barrel into the receiver. Finally, drive in the drift pins. Of course, the barrel must be aligned when metallic sights are used, and the headspace must be precise.

The table in Figure 21 gives the average dimensions of some popular rifles utilizing threadless barrels.

Make/Model	Tenon Length	Shoulder Diameter	Tenon Diameter	Type of Thread
Marlin Model 56 rifle	0.875	0.742	0.630	Not threaded
Marlin Model 57 rifle	0.875	0.742	0.630	Not threaded
Marlin Model 80 rifle	0.875	0.742	0.630	Not threaded
Marlin Model 100 rifle	0.875	0.750	0.630	Not threaded
Mossberg Model 46-M	1.600	0.745	0.639	Not threaded
Remington Model 500 series	1.010	0.765	0.604	Not threaded
Remington Model 513 rifle	1.000	0.867	0.600	Not threaded
Stevens Favorite rifle	1.536	0.740	0.665	Not threaded
Winchester Model 77	1.125	1.080	0.875	Not threaded

Figure 21: *Barrel tenon data for rifles with threadless barrels.*

Bushing and Barrel Preparation

The gunsmith specializing in custom pistol work will often encounter barrel and bushing adjustments on the Colt® Model 1911 pistol. There are many types of competition-style barrel bushings available, including matched or prefitted, undersized, and oversized. They are produced in chrome moly and stainless steel and are available in finger or full skirt styles. Be selective when choosing the size and style to ensure that it will closely satisfy your requirements. This will reduce fitting time required to prepare the bushing.

Note: For match-grade performance, avoid reworking standard bushings with expansion or swaging methods to obtain proper fit. This procedure is useful when addressing the requirements of a standard gun but should be considered inadequate to maintain match grade tolerances.

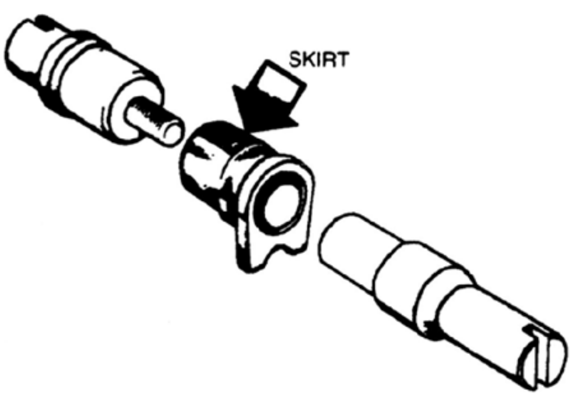

Figure 22: *Mandrel used during the process of bushing/ barrel preparation for the Colt Model 1911 pistol.*

Figure 23: *Brownells Colt bushing wrench.*

Prior to turning the outside diameter of the oversized bushing, check the bushing seat in the slide to ensure that it is true and free of irregularities. After determining the inside dimension of the seat, the outside skirt diameter can be turned to size. Using a two-piece mandrel to secure the bushing will facilitate this operation (Figure 22). The tapered center, in conjunction with the flat seat of the female mandrel, locates the front of the bushing and the hardened cone of the male retainer centers the rear for an accurate setup.

This threaded, two-piece mandrel can be fabricated from ¾ in. round stock. Two sections are required. The male and female threaded mandrels are defined in Legend I (Figure 24).

NOTE: The noncritical dimensions can be varied to meet your requirements. The reduced ½ in. shanks are optional and are provided if you are restricted to a 0.500 in. collet or a ½ in. chuck.

After the machining operation, final fitting is completed by hand. All edges are deburred and surfaces polished as the lug is fitted and honed for a full contact fit. This procedure will be facilitated by applying a layout fluid to indicate the tight areas. A bushing wrench (Figure 23) is used to gain the leverage necessary for hand fitting. This accessory will also be required by the shooter for both installation and removal of the match-fit bushing.

The illustrated version is a Colt Combo Wrench, which exhibits additional features to aid in the removal of the ratchets of both large and small frame Colt revolvers.

LEGEND 1

A 0.0570”
B 1/4-20 UNC 1.00” DEEP
C 0.500°*
D 0.750°*
E 1.375°*
F 0.500” SLOTTED SHANK
G 0.725°*
H 60-DEGREE CENTERING CONE
I BUSHING
J 45-DEGREE TAPER*
L 0.500” CENTERED DRILLED AND SLOTTED SHANK
M 0.500”
N 0.250°*
O 1.250”
P 60-DEGREE CENTERING CONE
Q 0.875”
R 0.675”
S 1/4-20 THREADED SHANK
T 0.4375°*
U BUSHING

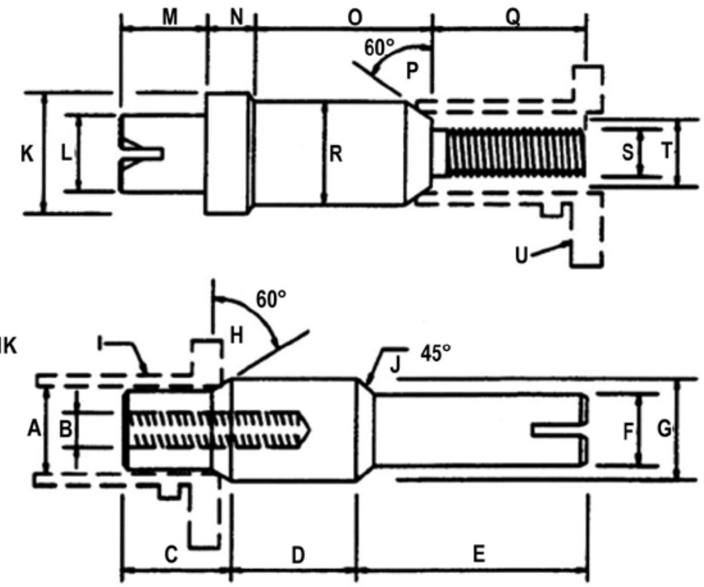

Figure 24: *The threaded two-piece mandrel can be fabricated from the 0.75 in. stock.*

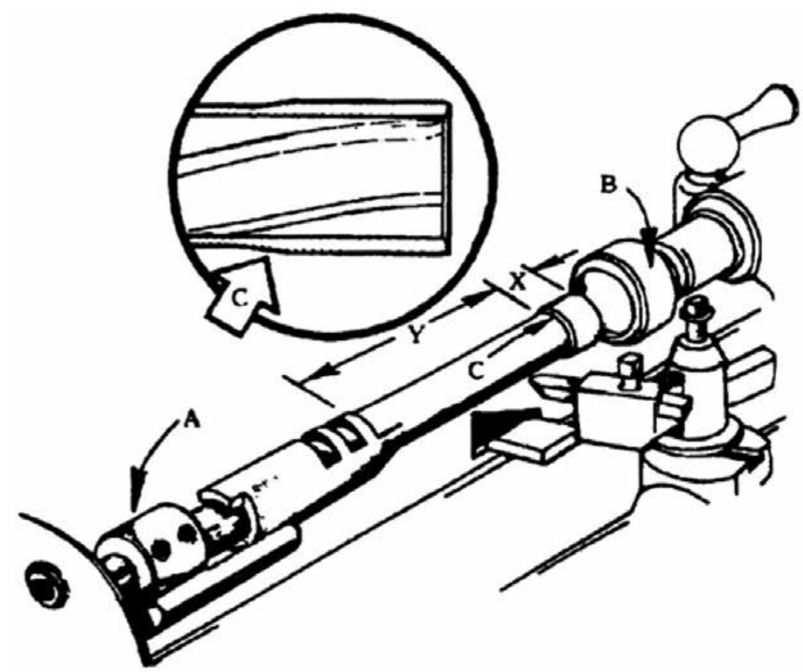

Figure 25: *An oversized barrel chucked in a lathe, ready to turn the outside diameter to the required dimensions.*

BARREL PREFIT PREPARATION

Most custom barrels exhibit acceptable machine finishes in areas that might not require prefitting. However, it is strongly suggested to check all critical areas to ensure that the finish specs meet your fitting requirements. First, inspect the locking lug areas to see that they are smooth and free of imperfections. The leading edge of the lugs should exhibit a light radius. The top surface of the barrel should be polished from the face of the barrel hood, including the top of the locking lugs. Visually inspect the muzzle, bore, and barrel lug areas to see that no defects exist. Next, check the barrel face, chamber area, and barrel hood to see that they are free of blemishes, although these areas will generally require refitting or alteration.

Figure 25 shows an oversized barrel chucked in a lathe ready to turn the outside diameter to the required dimensions. This fits the bushing and establishes proper clearance. The setup illustrates a centering mandrel, fitted with an adjustable dog “A” positioned to engage the barrel lug. The muzzle is secured on a live center “B,” which both locates and aligns the barrel. When turning the bearing surface of the muzzle end of the barrel, indicated by dimension “X,” remove only the metal required to ensure that the outer surface of the barrel is both true and concentric to the bore.

NOTE: After comparing the new muzzle dimension to that of the oversized bushing, reduce the muzzle diameter to retain additional bushing wall thickness. The length of this bearing surface should not exceed 0.500 in. and its profile

should be terminated with a gradual taper, indicated by arrow "C." This taper should blend into the relieved area of the barrel, designated by the "Y" dimension. This second cut should reduce the diameter of the barrel by 0.003- 0.005 in. to provide additional clearance, which eliminates drag and prevents binding. This relief cut can extend from the recess of the front locking lug to the taper of the bushing-bearing surface.

After this machining operation, the tapered surface area, designated by arrow "C" in the insert, should be honed. This ensures a smooth transition movement from the barrel through the bushing during the lock-up cycle.

To complete the prefit preparation of the barrel, polish the barrel above the chamber area, as shown in Figure 26. This operation can be performed using a cloth-backed abrasive. Start with an appropriate grit to remove any minor irregularities that might exist. Dress the barrel from the rear locking lug to the face of the barrel hood as indicated by the "shaded area" of the insert. Begin at arrow "X." Continue with progressively finer grits until completing the operation. The final polish should be made using 500- to 600-grit.

Do not alter the barrel profile at arrow "X" or lower the locking lug at this time.

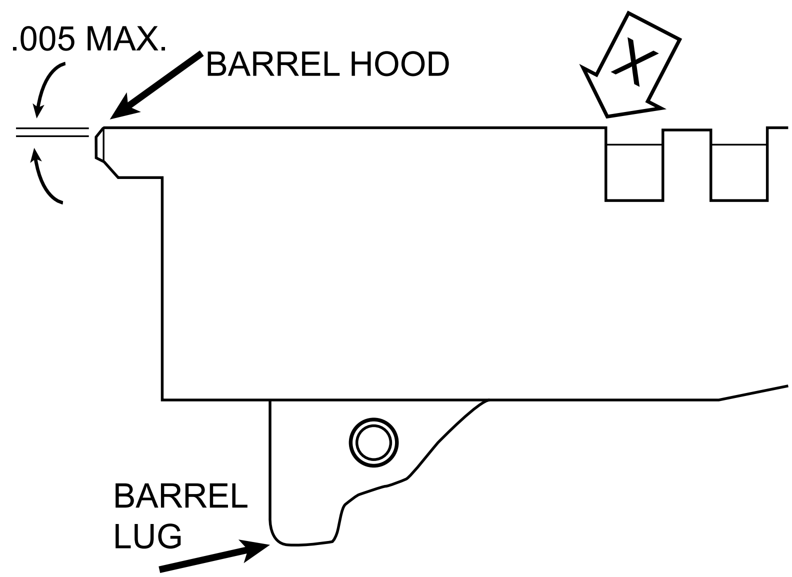

Figure 26: *To complete the prefit preparation of the barrel, polish and relieve the area immediately above the chamber.*

Headspace

Headspace is the measurement from the rear of the cartridge case to the face of the bolt. In general, if too little headspace is provided, the bolt will not close. If the bolt closes on the cartridge and there is too large a gap between the cartridge and bolt face of the rifle, the weapon has too much headspace. In this latter case, when the rifle is fired, the cartridge case stretches and will often separate, as shown in Figure 27(A), allowing harmful gas to escape to the rear of the case.

There are basically four different methods used to ensure proper headspace, all of which are shown in Figure 27. The cartridge in Figure 27(B) uses the rim of the case to obtain proper headspace. The front of the rim rests against the face of the barrel, while the rear side of the rim rests against the breechbolt. Thus, headspace on rimmed cartridges is determined by the distance from the face of the breechbolt to the face of the barrel, or barrel recess.

Figure 27(C) shows a rimless cartridge case. The shoulder of the case stops the cartridge from entering the chamber too far. Headspace gauges are designed to measure from the bolt face to the case shoulder.

Belted cases, like the one in Figure 27(D), utilize a raised belt around the rear of the case to obtain its headspace. When chambered, the case is stopped by the front edge of the belt.

The final type is the straight, rimless case, as shown in Figure 27(E). These cases are used in semi-automatic pistols. The headspace is measured from the face of the breechbolt to the front edge of the cartridge case.

A good rifle should have no more than a 0.006 in. variance in headspace to allow for the variance in ammunition cases. Even if the rifle comes from the factory with perfect headspace,

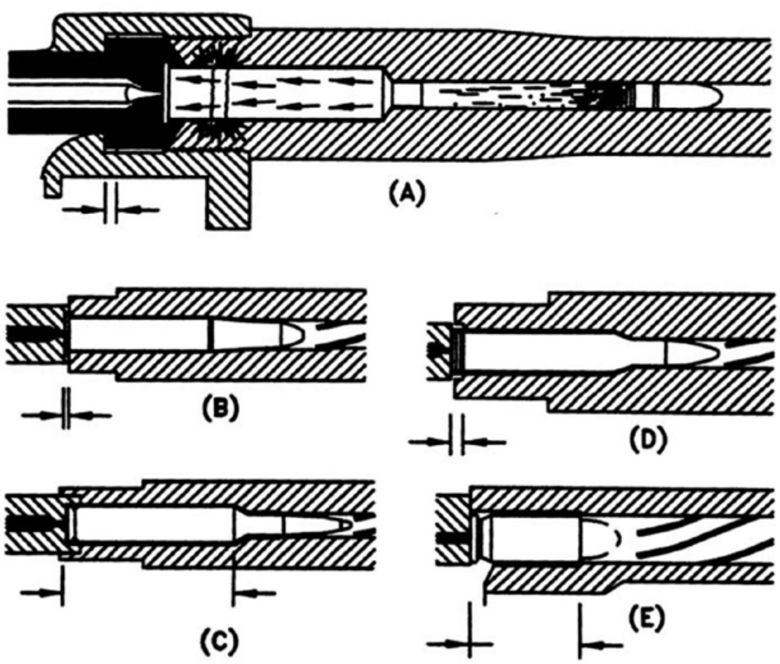

Figure 27: *Characteristics of headspace: Too much headspace (A) can cause separation; rimmed cases (B) use the front of the rim to check headspace; rimless cases (C) use shoulders to check headspace; belt cases (D) use the front edge of the belt to check headspace; straight rimless cases (E) use the front of case (mouth).*

it will change after the rifle has been fired several times. The main cause of the change in headspace is the wearing of the locking lug surfaces. As the rifle is fired, the movement of the bolt locking lugs and the pressure put on them when firing changes the fit and position of the locking lugs.

This action changes the position of the bolt face. When excessive headspace is found in a rifle, there are generally two ways to correct it: replace the breechbolt with one a little longer to compensate for the excessive headspace or set the barrel back one turn and rechamber.

Headspace gauges are steel, plug-like gauges. They test headspace in all types of firearms. They are designated Go, No-Go, and Field. For most gunsmithing work, you should have both the Go and No-Go gauges (Figure 28). In checking headspace, the action should close on the Go gauge. It should not close, without excessive force, on the No-Go gauge. If the action closes on the Field gauge, the rifle is extremely dangerous to fire.

Figure 28*: Three types of headspace gauges, from top to bottom: Go, No-Go, and Field.*

RIMFIRE HEADSPACE PROBLEMS

Contrary to popular belief, headspace can be critical in a .22 rimfire rifle. If the headspace is a bit short, a cartridge might fire from pressure since the bolt is closed. If the headspace is too long, ignition is uncertain and not uniform. In match rifles, like the Winchester Model 52, headspace should be limited to 0.044 - 0.045 in. The hunting arm can have broader tolerance — 0.043 - 0.046 in. Firing pin protrusion should be 0.045 in. Less protrusion causes non-uniform ignition, while more protrusion cuts a dent in the chamber and the firearm is snapped empty.

When inevitable wear causes a bolt to drop back a few thousandths of an inch, leading to excessive headspace, ignition will no longer be entirely uniform.

The .22 cartridge is so small that any variation in the flash of the primer can change the point of impact. With a small-bore ten-ring, .15 in. in diameter at 50 ft., a slight variation of headspace can cause a great difference between the aim and the actual target impact.

Each type of rifle presents its own problem when you start correcting headspace. Most of the .22 rimfire bolt-action rifles lock on the root of the bolt handle. In some instances it will be necessary to build up the root of the handle with a welding torch and then file it to fit. Quite commonly, though, one will need to correct the older and better-quality .22 match rifles such as the Winchester Model 52. On this rifle, the bolt body can be separated and a very thin shim placed between the sections to move the forward portion of the bolt ahead.

CHAMBER CHECK FOR COLT MODEL 1911

After you have achieved the proper barrel, frame, and slide fit for the Colt Model 1911 semi-automatic pistol, the chamber lengths should be checked for proper headspace. You can confirm the correct headspace tolerance by using both Go and No-Go headspace gauges (Figure 29).

Note: The .45 ACP is a rimless straight case that headspaces off the case mouth. The nominal chamber length is 0.898 in. You can confirm by carefully chambering the Go headspace gauge. This initial test confirms that the chamber is the proper length. To further establish that there is no excessive length, insert the No-Go gauge and ease the slide down. If this gauge prevents the barrel from locking up, the correct headspace has been attained.

Usually, this procedure confirms that you have maintained proper chamber tolerances. However, if the fitting operation resulted in a tight chamber, you should use a chambering reamer to return the chamber to its correct dimension. This procedure can be completed by hand using a finishing reamer (Figure 30). Work slowly, using multiple, light passes to recut the chamber to the required depth. Check your progress frequently with the headspace gauges. Remove the reamer carefully and clear the chamber area each time before inserting the No-Go gauge. As you near the correct chamber depth, the barrel will move into lock-up position. To complete the operation, confirm the chamber dimension with the Go gauge. An excellent source for both chambering reamers and headspace gauges is Clymer Manufacturing.

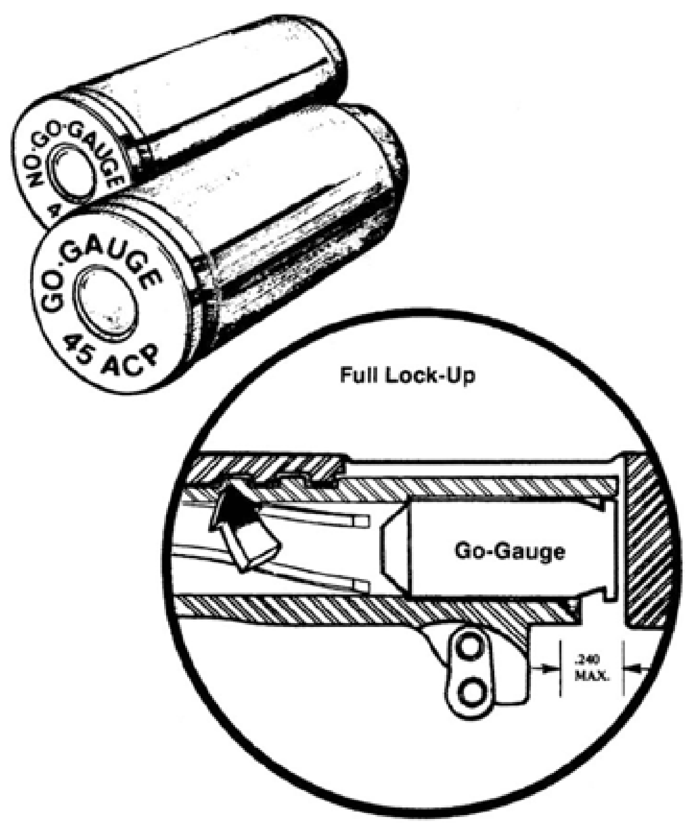

Figure 29: *Once the barrel/frame/slide relationship is determined, check the work with headspace gauges.*

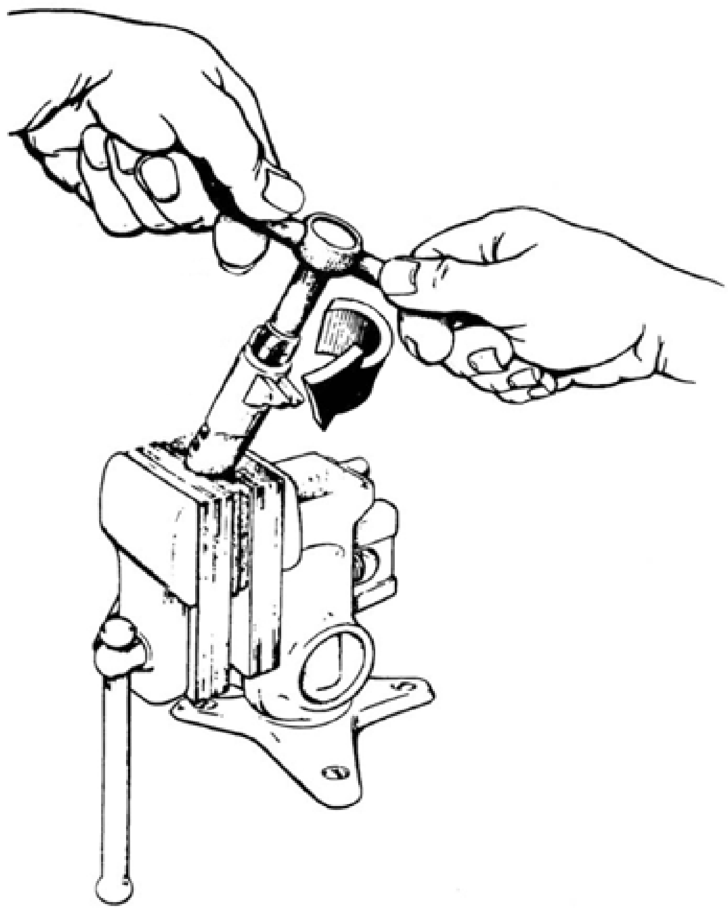

Figure 30: *It might be necessary to use a chambering reamer to correct chamber dimensions.*

NOTES

NOTES

Chapter 6 - Chambering, Free Boring, and Trigger Work

Introduction

When the trigger on a firearm is pulled, it releases the firing pin to ignite the cartridge primer. This part was originally called "the tricker" because when pulled it "did the trick."

When a trigger is pulled, increasing pressure is applied until the sear is disengaged, allowing the firing pin to fall against the cartridge primer, which in turn ignites the powder to push the bullet out of the muzzle. Effective trigger squeeze requires proper follow-through. By avoiding the natural inclination to jerk or flinch at the moment the sear is released, the shooter reduces gun disturbance (and improves the aim).

For this reason, proper trigger squeeze is very important for obtaining the best accuracy. Just as important is the distance and pressure required to move the trigger enough to release the sear.

The adjustment of trigger pull is a job that many gunsmiths frequently encounter and one that every potential professional should learn as soon as possible.

Practically every rifle needs some smoothing or adjusting to meet the demands of the more serious shooter, since good accuracy depends a great deal upon perfect trigger control. It stands to reason that a trigger cannot be perfectly controlled if it drags, jumps, creeps, or varies in the amount of pull required to release the hammer or plunger.

Experience has shown that the best trigger pull for general use requires a pressure on the trigger ranging from 2½ to 4 lb. to discharge the rifle. Some shooters prefer a lighter pull, but a lighter pull can be dangerous unless the rifle is designed strictly for target and benchrest shooting. A clean, crisp trigger pull is most important; the trigger should not move at all until it releases the firing pin or plunger. Then it should give way suddenly without any preliminary movement. This is the type of trigger pull that the gunsmith should seek when making adjustments.

Triggers

Trigger mechanisms usually consist of three essential parts, not including springs and pins:

- Hammer (cocking piece, plunger, or striker)
- Sear
- Trigger

In all cases, the hammer is held in a cocked position by the sear engaging in a notch. The sear may be a separate part or it may be the upper end of the trigger itself. The quality of any trigger pull is determined by the bearing surface smoothness of these three interacting components.

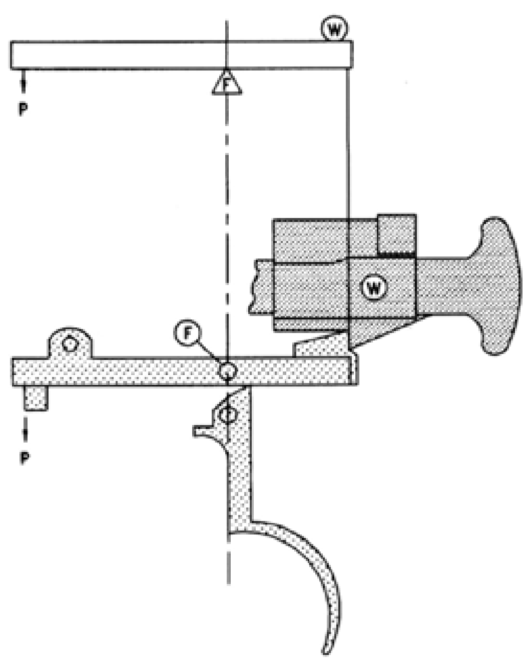

__Figure 1__: Operating principles of a two-stage trigger mechanism.

In mechanisms in which the sear functions as an integral part of the trigger, the trigger is pivoted by means of a pin or screw between the upper end, which forms the sear, and the lower end, to which the pressure is applied. This type of trigger operates on the primary-lever principle with the trigger becoming a lever, the sear forming the weight, and the pin or screw acting as the pivot point, or fulcrum. The finger supplies the power at the lower end.

When a separate sear is interposed between the trigger and hammer or striker as shown in Figure 1, a dual-leverage system is formed, and the trigger is usually a secondary lever. As shown in Figure 1, the weight (W) is located between the fulcrum (F) and the power (P) and is transmitted to the trigger through the sear. The sear may be either a primary or secondary lever, according to the design of the mechanism.

Figure 2 shows various classes of lever principles. In all three examples, the closer the fulcrum is to the weight, the less pressure is required for movement. When applying these principles to trigger mechanisms, the closer the pivot point of the trigger is to the cocking piece, the less

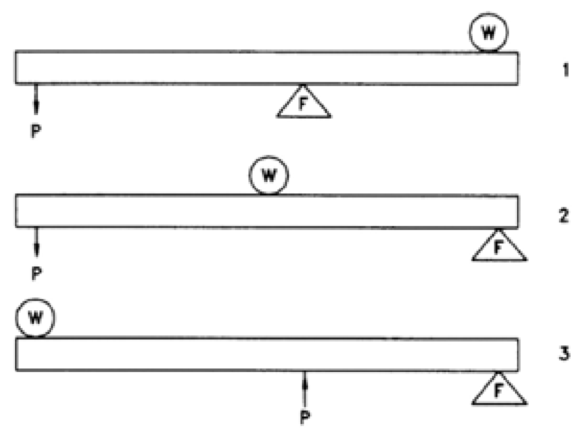

__Figure 2__: Various classes of lever principles.

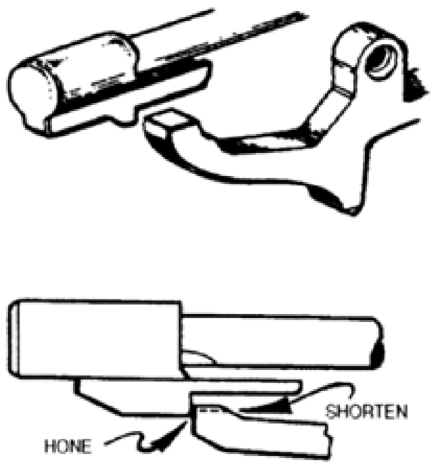

Figure 3*: Areas of a simple trigger mechanism (sear and cocking piece) to adjust for smooth trigger pull.*

trigger pull is required. However, the lighter the trigger pull (in a two-stage trigger mechanism), the longer the trigger travel and the greater the creep. *Creep* is the first stage of the trigger's travel to the rear, usually requiring a pull weight of 1-3 lb. Then to release the sear for firing, a separate 3-6 lb. of pull weight is required.

There are several types of triggers used today, all operating on a similar but slightly different principle. For example, triggers used on military rifles like the Krag, Springfield, Enfield, and Mauser are always two-stage designs and are noted for creep and hard pull.

The main advantage of this two-stage trigger is safety. Two-stage triggers are difficult to discharge if jolted or bumped, or if handled clumsily by new, untrained recruits.

Bolt-action rifle trigger mechanisms are controlled by the bearing surface smoothness of three interacting components: the cocking piece, the trigger sear, and the trigger. When the bolt of such a rifle is forced forward and shot, the cocking piece pushes hard against the sear. The contact surfaces of the cocking piece and the sear must be large and strong to stand the wear and to prevent the cocking piece from slipping and causing an accidental discharge of the rifle when closing the breech. The trigger is arranged to have two distinct motions. During the first motion, the trigger moves to the rear quite easily when about 1½ lb. of pressure is applied. This is the creep we mentioned previously. During this creep, the sear is lowered in its contact with the cocking piece until it rests against the nose of the cocking piece very slightly, just like a conventional trigger sear resting in a hammer notch.

To lighten a bolt-action rifle trigger pull, and also to eliminate creep and drag, you should first polish the contact surfaces of the sear and cocking piece where they come in contact with each other. This is best done with honing stones, but be careful not to take off too much metal at one time. Until you have several hours of experience, this polishing should be done very sparingly, trying the trigger for "feel" every few strokes of the stone. Do not attempt to change the angle too much at this stage. Simply polish the contact points so that they will slide evenly over each other without any grate.

The next step is to make this slide shorter, which is done by grinding the top of the sear as shown in Figure 3. Again, go slowly, reassembling and trying the parts frequently. You can always take off more metal, but it is hard to put it back on. It is also necessary, in some cases, to lighten the tension slightly of the sear spring,

which is usually a coil spring. To lighten, merely cut off one coil at a time until the right tension is felt, as shown in Figure 4. In some rare cases, this spring will be too light and will have to be strengthened. To do so, use a pair of pliers and a vise to stretch or lengthen the spring.

When any trigger repair is done, the entire trigger and safety mechanism must be tested several times to make certain that the rifle will not fire accidentally if you hit the butt against the floor. Do not pound the rifle butt against a hard object—just a few light taps should do it. Of course, the gun should not be loaded. Never load a gun with live ammunition while it is being repaired or tested in this manner.

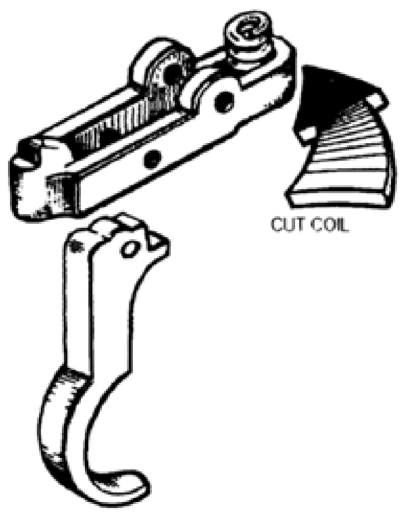

Figure 4*: Most sear springs on older military rifles may be lightened by merely cutting off a coil or two.*

Another type of military trigger utilizes two fulcrums (also called humps) at the top of the trigger. The forward hump is responsible for the first-stage creep as it pivots against the underside of the receiver, creating a drag or creep. Its main purpose is to slow down the cocking piece let-off and let the shooter know that firing is just a hump away. Creep on this type of trigger can be eliminated by grinding off this forward hump.

In doing so, the trigger sear will rise slightly higher against the cocking piece sear and provide a little more bearing surface. This will usually correct the problem of a rifle accidentally firing when the bolt is closed. Once the forward hump has been removed, the creep will disappear, but the trigger pull will be harder since the bearing weight has been increased. This problem can be corrected by slightly rounding the rear hump with a soft Arkansas stone. Again, this operation should be done gradually with many trials during the process. If too much metal is removed at this point, the rifle may fire on closing the bolt. With this slight alteration, plus a final polishing of all bearing surfaces, the trigger should have a medium-light crisp pull.

Again, when you complete the alteration, thoroughly test the gun (unloaded) to ensure that it will not accidentally discharge.

One of the easiest ways to improve the pull on a military trigger is by using a Viggo Miller military trigger attachment, which is designed to eliminate creep and enable the depth of the trigger sear engagement to be adjusted.

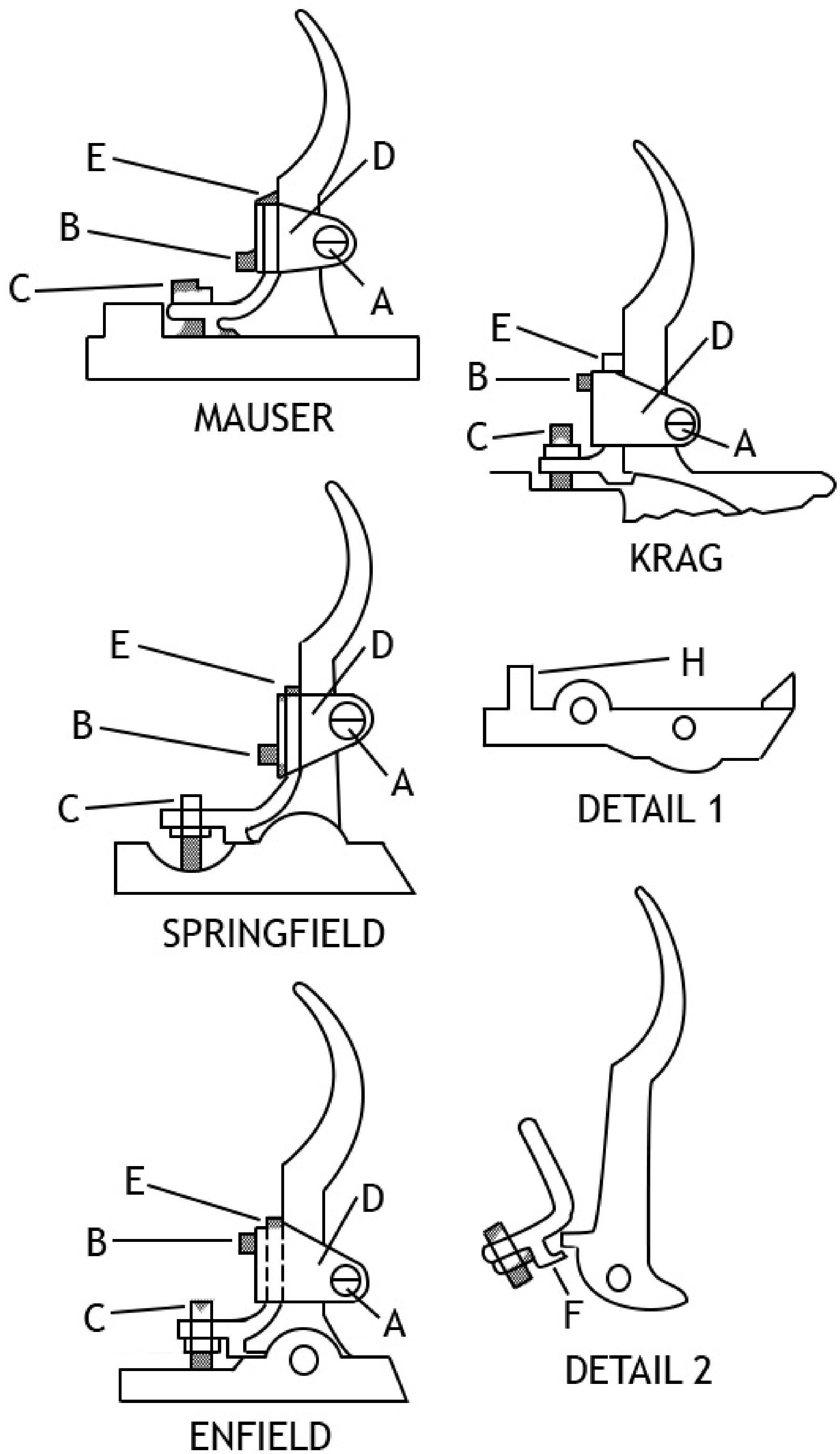

***Figure 5**: Viggo Miller's simple trigger attachment to improve trigger pulls on military rifles.*

For example, to attach one of these devices to the trigger mechanism of a .30-40 Krag rifle, remove the stock from the metal parts to allow complete access to the action and trigger mechanism (Figure 5). Hook adjusting bracket E into the slot at the base of the trigger. Back-screw B out from the clamp piece until it is flush with the inside of the clamp (D). Next remove screw A from the clamp so that the clamp can be slipped over bracket E. Afterward, replace screw A. The trigger of the .30-40 Krag is tapered, and if the clamp is at the upper part of the taper, it will be easier to insert screw A. Then push the clamp down toward the lower end on the taper, being sure that the lip on the bracket remains tight against the base of the trigger. Tighten screw B first; then tighten screw A.

To adjust the trigger, turn adjusting screw C in or out as needed to obtain the desired trigger pull; lock adjusting screw C with the locknut.

If there is not enough clearance around the trigger well of the gunstock to accommodate the attachment, remove some of the wood in this area with a stock-maker's chisel.

Since trigger mechanisms on other types of military rifles vary slightly, the procedure for installing the trigger attachment also will vary. However, complete installation instructions accompany each individual attachment.

TRIGGER REPLACEMENT

For ultimate speed, safety, and accuracy in a converted military weapon, many gunsmiths prefer to replace the issue trigger with a new, easily adjustable trigger mechanism. These mechanisms are available from gunsmith suppliers. In most cases, only minor alterations are required to replace the issue trigger with the more modern one.

Dayton-Traister, Inc. manufactures an all-steel trigger mechanism with case-hardened operating parts, expertly honed to deliver crisp, uniform trigger pulls every time. These are available from Brownells. The tempered, treated, and blued springs resist corrosion and fatigue, and the grooved finger area helps provide a nonslip finger grip. Trigger mechanisms are commonly available for most military weapons and sporting arms.

Custom trigger mechanisms normally are adjustable from 2 to 6 lb. to give a converted military rifle a faster lock-time and to increase the accuracy with a uniform, crisp trigger pull.

SINGLE-STATE TRIGGERS

Next comes the plain single-stage trigger found on many single-shot shotguns and hammer rifles such as the Winchester Model 94 or the Marlin Model 336. This type of trigger is either entirely loose in its guard or entirely stationary. When squeezed, the trigger remains stationary until it releases the hammer or firing pin; then it gives way suddenly, discharging the rifle. Many of these triggers come with a very hard pull of up to 8 lb., which is too much for any rifle. Some of these triggers also have a drag or creep, giving way slightly after a pound or two of pressure is applied. The perfect trigger squeeze is one that does not move at all until it releases the hammer or cocking piece.

To lighten and smooth this type of trigger, you will need a set of Arkansas stones of different shapes, a sheet or two of fine emery paper and crocus cloth, and a small trigger scale to measure the weight of pull. You will also need disassembly tools and a magnifying glass.

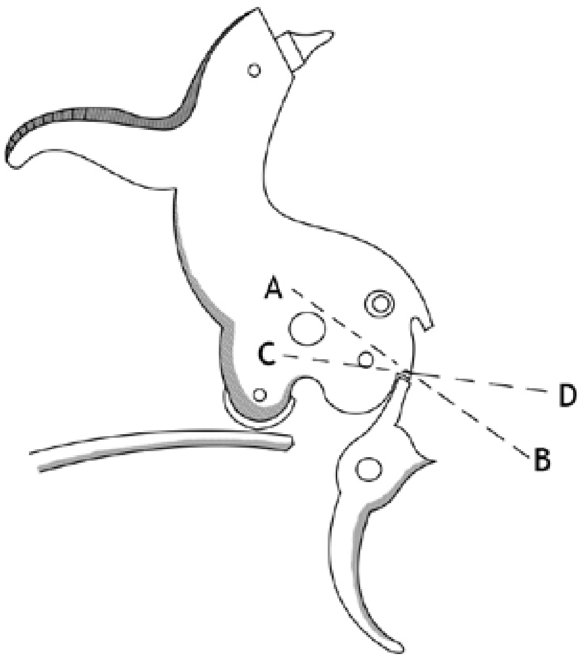

__Figure 6__: Changing the angle of contact from A-B to C-D will usually lighten trigger pulls on simple trigger mechanisms.

Figure 6 shows the trigger, the hammer, and the half-cock and full-cock notches in the hammer of a plain trigger. In this case, the trigger and sear are combined, but in some guns the trigger and sear are separate pieces.

First, examine the surfaces of the sear and hammer notches to determine the angle at which they meet each other. If the pull is heavy, the surfaces will probably come into contact like the dotted line A-B in Figure 6, showing that the sear, in order to release itself from the hammer notch, must act strongly against the tension of the hammer mainspring. This causes the heavy trigger pull. Also, the sear may be too deep in the notch, requiring much lifting before it disengages itself.

Remove the hammer and sear from the action and use the Arkansas stones to hone the two contact surfaces so the angle of contact will be changed to that shown by the line C-D in the illustration. During the honing, check the fit frequently to ensure that the surfaces will fit exactly when reassembled. The honing must also be done straight; that is, you should hone no more on either side than in the middle.

Go very slowly, assembling the parts often to test the weight of the trigger pull by the trigger scale. Watch the scale as the pull is applied, and notice the maximum figure on the trigger pull gauge just before the trigger gives way. As you get down to within a pound or so of the desired pull, be extremely careful, since frequently three or four more strokes of the honing stone will be all that is required.

In most cases, the above operation is all that is required to get a good trigger pull from this type of trigger mechanism, but in some cases the sear may take too deep a bite in the hammer notch. When this occurs, work only on the sear — not the hammer notch. If the hammer notches are not perfect, there is a good chance that, upon releasing the sear, the hammer will catch in the half-cock as it falls, preventing the gun from firing consistently. One way to prevent the sear from entering into the notch too deeply is to use a small center punch to raise a small crater just in the rear of the notch, as shown in Figure 7. The sear will then strike against the raised portions of the metal around the crater and will not settle down as deeply in the notch.

If the raised portions of the crater are too high, the situation is easily corrected with a few strokes of the honing stone over them. This cratering will also eliminate the majority of trigger creep, since this is usually due to the sear entering the

notch too deeply. If it does not eliminate creep, then it is because the contact surfaces of the sear and notch are not smooth enough; this can be corrected by honing both surfaces smooth.

Set triggers have been used on both sporting and target rifles for quite some time. The first ones used on modern sporting arms were on the Mannlicher rifles manufactured around the turn of the century, although the Winchester® Repeating Arms Company first offered set triggers on their Model 1873 lever-action rifles. There are many kinds of set triggers, but the most common contain two triggers within the trigger guard, as shown in Figure 8. The front trigger, when pulled alone, operates like a normal trigger. But when the rear trigger is pulled first (until it clicks), the front trigger is then set, and upon touching the front trigger with only an ounce or so of pressure, releases the hammer or cocking piece. This is truly a "hair trigger," and the trigger should never be set until the gun is ready to be fired. Another type of set trigger

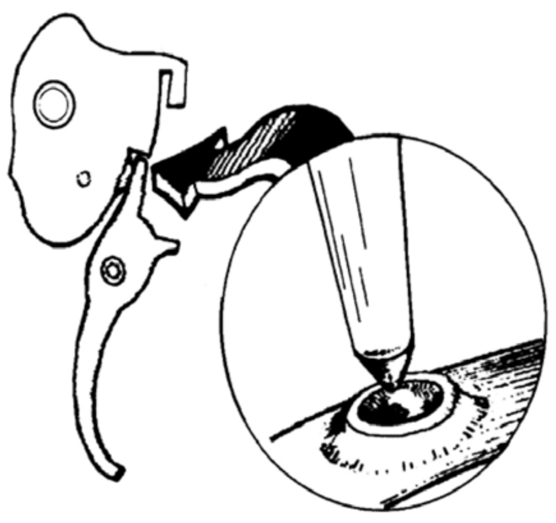

Figure 7: Cratering the contact area on the hammer notch of simple trigger mechanisms will prevent the sear from entering the hammer notch too deeply.

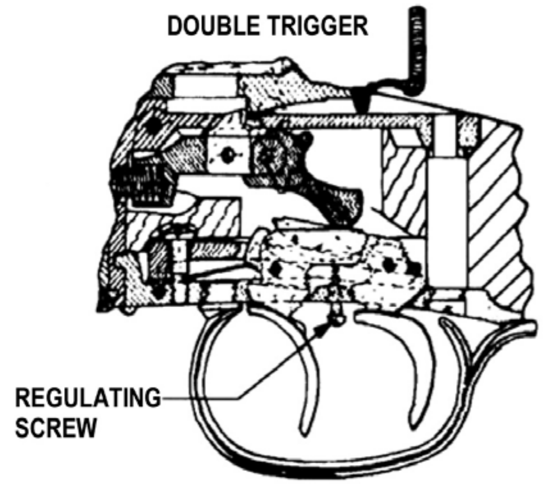

Figure 8: The double-set trigger mechanism found on European-type bolt-action rifles.

contains only one trigger. When this is pulled rearward, ordinary pressure is required to release the hammer. However, when the trigger is first pushed forward until it clicks, this sets the rearward movement, which will release on a very minute amount of pressure.

Many of the muzzleloading rifles of the past century utilized a set trigger, and this practice has been carried over on the modern reproductions of these rifles. Nearly all are adjustable by means of two adjusting screws, either in the lock or on the outside of the rifle near the triggers.

The mechanical actions of all set triggers are very similar in that the action of setting compresses and locks back a strong lever or hammer. The sear of this hammer is attached to the front trigger and is very delicate. On touching the front trigger, this sear releases the hammer or lever, which then flies up and, with a blow, drives the true sear away from the true hammer or cocking piece, causing the firearm to discharge.

HANDGUN TRIGGERS

Early handgun triggers were nearly all similar to the plain trigger used on most shotguns and hammer-type rifles, and the instructions given for these also apply to the handgun triggers. This, of course, applies only to single-action revolvers like the Colt Peacemaker and others. Double-action revolvers, when used in the double-action mode, depend a great deal on the strength of the mainspring and its tension on the hammer as to the amount of trigger pull required. Brownells offers several spring kits for various handguns, and any of them will greatly improve trigger pull and hammer slap. For example, the Bullseye Kit No. 2 is designed for the Colt MK III series revolvers and consists of a new hammer and trigger spring, which are designed to lighten both the double- and single-action functions without any other work or adjustments to the revolver. Since the double-action trigger pull on these revolvers is almost legendary in the industry, this modification kit will do wonders for the revolver's trigger pull, improving accuracy and eliminating jerking. Kits are also available for other models such as Ruger®, S&W®, Browning®, Dan Wesson®, etc. Figure 9 shows a typical single-action revolver trigger assembly.

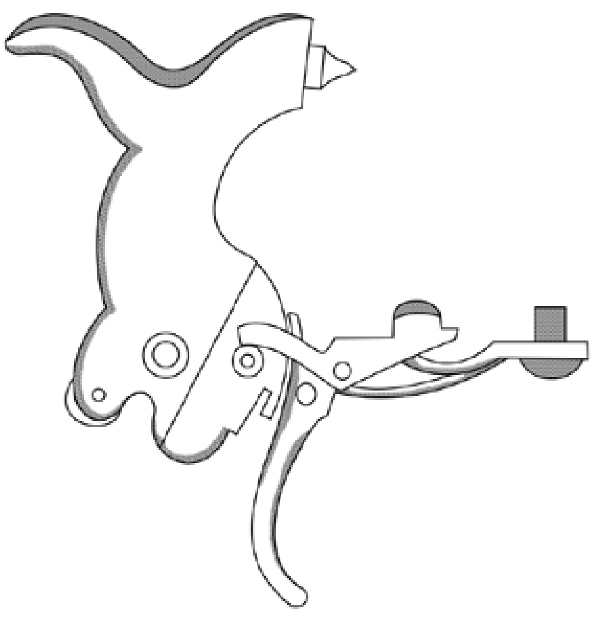

Figure 9*: Typical single-action revolver trigger assembly. This is the style used on the Colt, Ruger, and other brands of single-action revolvers.*

Some of the older handguns, especially double-action revolvers, had their trigger pull lightened by grinding the mainspring to make it thinner and easier to operate. However, this practice also made the mainspring weaker, and misfires were frequent. Other types of revolvers have a small screw on the front of the grip-frame near the bottom of the handle. This is a strain screw that is used for applying tension to the mainspring. Some people have tried to lighten the trigger pull by loosening this screw, but this almost always causes trouble. This screw needs to be tight to cause the mainspring to lie with the proper curve; otherwise, the action of the revolver will be impaired.

Semi-automatic pistols such as the Colt .45, Browning, Star®, Savage Arms®, and others can have their trigger pull improved, but care must be taken in this area when altering the trigger. If a very delicate trigger pull is obtained, a jar of the action may cause the hammer to follow the slide, **resulting in an automatic-firing weapon, which is both dangerous and illegal.**

Trigger sears and hammers on automatic pistols are honed in much the same way as the firing mechanism on shotguns and exposed hammer rifles. But after the adjustment has been made, the pistol should be tested by cocking the hammer and, with the finger off the trigger and the grip safety compressed, drawing back the slide and allowing it to slam forward several times as violently as possible. If the hammer follows the slide (fails to stay cocked), the pull is obviously too light.

A light pull can sometimes be corrected by increasing the tension on the sear spring by bending it, but in most cases it is best to order a new hammer and sear and start over. Take great care in honing these parts of the automatic pistol to avoid making this mistake.

Semi-automatic pistols with no hammer exposed usually have a sear that engages a shoulder or notch in the plunger or firing pin. Most of these weapons have a heavy, dragging pull, which in some constructions cannot be overcome due to the leverage employed in the design. In other types, it can be somewhat improved by carefully honing the contact surfaces so that they will slide evenly and smoothly. In general, the depth of contact or the angle of the surfaces should not be changed, since in many semi-automatic pistols — especially of foreign make — the safety only prevents the trigger from being pulled, but does not prevent the sear from jarring out of engagement with the firing pin if the gun is dropped. When these pistols are loaded they are always cocked, and to alter the sear or firing pin might render the pistol extremely dangerous to carry loaded. For this and other reasons, it is good practice never to load a round into the chamber of a semi-automatic pistol until the gun is ready to be fired. Just slide the magazine into its place in the grip, but do not chamber a round. When firing is completed, unload the pistol and make sure the chamber is empty.

TRIGGERS FOR MUZZLELOADERS

Those who have cleaned up and restored an old muzzleloader to firing condition can tell you that the trigger pull on these weapons leaves a lot to be desired. Even the modern reproduction models often have an extremely hard and rough trigger pull so that good accuracy is almost impossible. However, nearly all of these trigger mechanisms can be improved relatively easily — provided you have patience.

To smooth up the trigger pull on one of these guns, disassemble the lock from the stock to gain access to the mechanism. Use only screwdrivers that fit the screw slots exactly, and on older models (which will probably be rusted) use plenty of penetrating oil to help loosen the screws. Using a spring vise, remove the mainspring from the lock and then release the sear. Cycle the action a number of times until you are thoroughly familiar with the interaction of each part. You may now wish to make a sketch or take a close-up photo of the lock parts intact to ensure that it can be assembled correctly at a later date. At this time, examine each part very carefully, looking for any burrs or drag marks indicating which areas should be honed for a smoother action. Make a note of your findings and then disassemble the parts that need to be worked on. Again, older locks may require soaking in a penetrating oil or kerosene to enable the screws or pins to be removed without damage.

Once the lock has been disassembled, clean all oil and debris from the back side of the lockplate and then examine it carefully. Chances are you will find a rough surface, left just as it was when cast. First use a No .2 cut mill file to smooth the worst of this roughness down, ending up with various grits of wet-or-dry abrasive paper for the final polishing. Also polish the side of the tumbler and sear at this time. You will also want to check the space between the bridle and the lockplate to see if it is too wide. If it is, file the shoulder of the bridle at the point it makes contact with the lockplate, until just enough room remains for the tumbler to rotate without binding.

In many muzzleloading rifles, the sear is somewhat narrower than the tumbler, causing excessive side play even when the bridle is snugged up tight on the tumbler. This problem can be corrected by inserting a thin washer next to the lockplate to shim the sear.

Next examine the hammer. Sometimes it will be canted and dragging against the lockplate, or there may be excessive play between the hammer and lockplate. If this is the case, file the square hole (or peen, whatever the case may be) to make the hammer stand parallel to the lockplate without too wide a gap.

Hone the sear and sear notch in the tumbler with a three-cornered Arkansas stone. In doing so, keep the sear surfaces square and parallel to retain full contact across their entire width. After establishing the correct sear angles, polish the sear as discussed previously, but be careful not to deepen the sear notch on the tumbler during the process. To remove any creep, drill a very small hole in the tumbler, just below the sear notch and press-fit a small pin that will fit snugly into the drilled hole. Then file the pin back just enough to allow a safe sear engagement. Never file down the top of the sear notch on the tumbler to reduce creep. This will usually cause the sear to catch on the half-cock notch as the tumbler rotates in firing.

The strong springs in the older muzzleloaders were the chief cause of a heavy trigger pull. This was the main reason for set triggers. In most cases it is best to replace the old spring with a new, lighter one. However, if the old spring is in good condition, it can be lightened considerably by using a small grinding wheel in one of the rotary tools, carefully grinding the spring lengthwise until the desired tension is attained. You do not want to grind the spring to the point where it might break or be so weak that misfires may result.

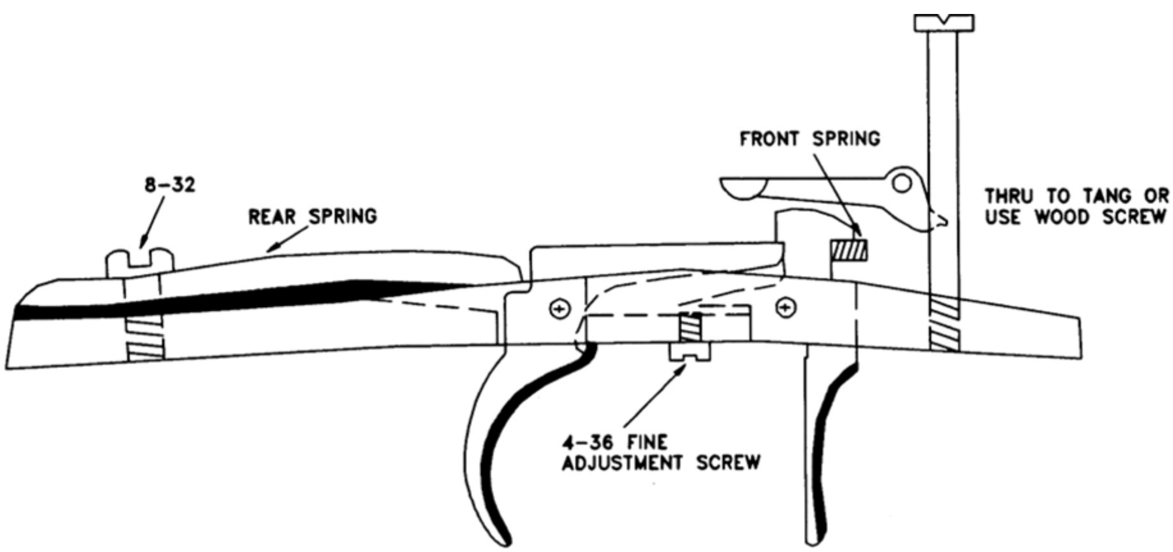

***Figure 10**: Typical black powder double-set trigger mechanism. Note the trigger adjustment screw between the front and rear trigger. The screw adjusts the pressure required to release the true sear when the front trigger is touched.*

Once all of the surfaces have been polished, they will wear much longer if hardened by first heating the part to cherry red and then dipping the part into commercial hardening compound such as Kasenit, and then reheating it. Use a wire brush to clean the scale off the part and then lightly polish it before reassembling it. Of course, a spring cannot be hardened further once the proper temper has been reached. Only mating surfaces, such as sears, should be hardened. Then use your notes and sketches to reassemble the lock. Test and adjust accordingly. Figure 10 shows a typical black powder double-set trigger mechanism.

ADJUSTING FACTORY TRIGGERS

Most of the better centerfire rifles manufactured today come with adjustable trigger mechanisms. The Sako trigger assembly, for example, is factory set for perfect sear engagement. The weight of pull and backlash can be adjusted simply and positively without too much trouble. Look at the illustration in Figure 11 and then make the following adjustments:

- To lessen the weight of pull, loosen locknut A and turn screw B until the desired weight of trigger pull is reached. Then again tighten locknut A.
- To increase the weight of pull, reverse the above procedure.
- Backlash may be reduced by turning the end screw.

Make sure that all remaining screws are tight before attempting any of the adjustments just described. Other makes of trigger assemblies may be adjusted in a similar way; adjustment instructions normally accompany the firearm.

INSTALLING NEW ADJUSTABLE TRIGGERS

Custom rifles built on military rifle actions, such as Mauser, Springfield, Enfield, etc., normally have their trigger mechanisms replaced with adjustable, single-stage replacement triggers. Some of the more popular brands are those manufactured by Dayton-Traister, Timney, and N.O.C. All of these usually require some fitting, with honing stones and small files. Also, wood

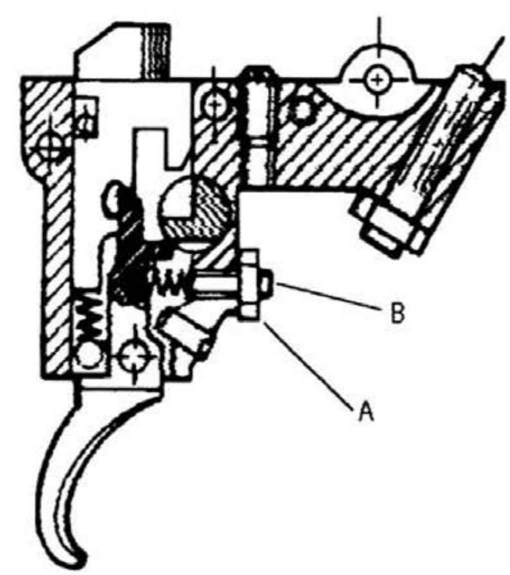

***Figure 11**: Trigger assembly for Sako bolt-action rifle showing points of adjustment.*

must be removed from the trigger recess in the rifle stock. Some of these, especially set trigger assemblies, also require modification of the trigger guard and floor plate. There are really no set instructions that can be given to install these trigger assemblies perfectly each time. It is a matter of trial-and-error: the trigger is tried in position on the receiver; tight areas are noted; these areas are honed down; and then the trigger is retried. Once the trigger assembly operates perfectly with the rifle's action, the barreled action and trigger assembly are lowered into the stock. When an obstacle or tight resistance is met, a portion of the wood is removed in much the same way as when inletting a stock for a barreled action.

The importance of a good, crisp trigger pull cannot be stressed too much if the best possible accuracy is desired. Trigger work is often thought of as a highly specialized field suitable only for the professional gunsmith. While this statement is partially true, there is no reason why a seasoned hobbyist cannot obtain good results, provided the work is taken slowly, that every move is carefully analyzed first, and that care is taken to obtain the best workmanship possible. It is suggested that the beginner's first project be done on a cheap military trigger mechanism before attempting any such adjustment on a more valuable firearm. When you have sufficient experience, you may then progress to more complex trigger adjustments on more expensive weapons.

Chambering

CHAMBERING REAMERS

In general, there are three types of chambering reamers: the rougher, the finish reamer, and the burnishing reamer. The rougher is designed to cut out a lot of steel fast, and gives only approximate chamber dimensions. If all three types of reamers are used, this is the one that will be used first. Next comes the finishing reamer, which cuts the roughed-out hole in the barrel (made with the rougher) to exact chamber dimensions. The burnishing reamer exerts only a scraping and polishing action. It is used as a final step to give a glass-smooth finish to very fine barrels. It will remove no appreciable amount of steel.

Chambering reamers are not cheap. They cost anywhere from $50 to $100 each, depending on the type. Therefore, the average gunsmith will try to get by with just the finishing reamer. This practice is okay in some cases, but it is a waste of time and money in others. If you are chambering a .45 caliber barrel, for example, to .45-70, there is not much metal that has to be removed, since the .45-70 cartridge is almost a straight case with very little taper. In this case, the finishing reamer will do very nicely for the entire job, and will remain sharp (if correctly oiled) for several chambering jobs. At the other extreme would be chambering a .25 caliber barrel to accept the .257 Weatherby cartridge. In this case, there is a lot of metal that needs to be taken away to accept this big Magnum case in comparison to the small .25 caliber bore, and if the job is done only with a finishing reamer, the reamer would probably get too dull to cut before the full chamber dimensions were reached. In this latter case, you definitely want to use a rougher first (Figure 12).

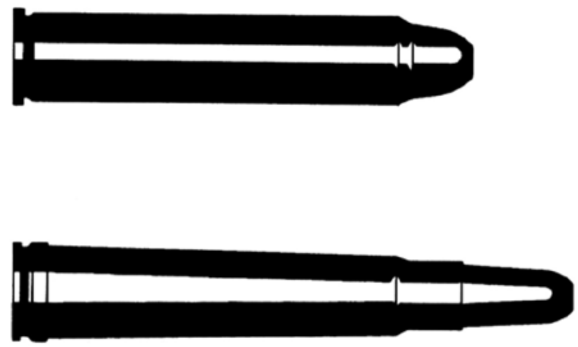

Figure 12: *It stands to reason that the straight cartridge case (top) requires less cutting than the bottleneck cartridge case (bottom).*

However, to save the expense of purchasing a rougher, some experienced gunsmiths use an undersized twist drill to remove excess metal from the chamber area before using the finishing reamer to cut the chamber to exact dimensions. This is fine if you know what you are doing, but it is also a good way to get the chamber off center to the bore, and possibly ruin the job completely.

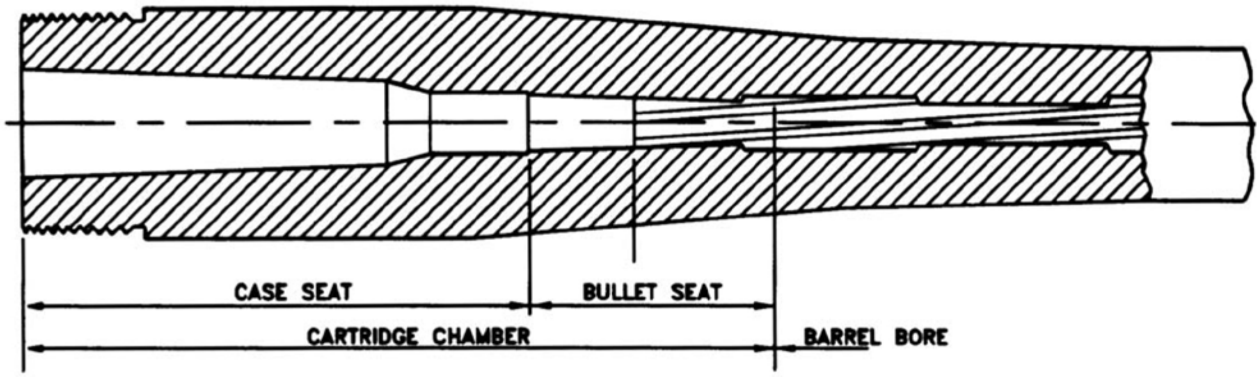

Figure 13: *Cross-section of a rifle barrel, showing case seat, bullet seat, and barrel bore.*

Look at the cross-sectional view of a rifle barrel shown in Figure 13. Notice that the chamber section (cartridge chamber) begins at the breech end of the barrel (the left-hand end with the barrel threads) and extends toward the muzzle through the bullet seat area. This area is what a chambering reamer cuts. With these facts in mind, let us see how the chamber of a rifle barrel is cut.

To chamber the barrel, chuck the muzzle end of the barrel in the lathe's 3-jaw chuck, using a lathe center in the tailstock at the chamber end to align the barrel perfectly between centers. Then use a steady rest on the lathe bed to secure the barrel in this position once the tailstock is removed for actual chambering. A dial indicator must be used here to ensure perfect alignment. Once the steady rest and barrel have been secured, remove the tailstock center from the chamber end and insert a drill chuck, with the chambering reamer in the tailstock where the center had been.

Adjust the lathe to run on its lowest speed and start the barrel rotating. Carefully oil the reamer with clean cutting oil and slowly start the reamer into the chamber area. Depending upon the size of cut, let the reamer cut to a depth of about ½ in. before removing it from the chamber to be cleaned and re-oiled. In doing so, never reverse the reamer in the chamber; always keep it turning in a clockwise direction. Since the reamer remains stationary, this means the barrel must turn in a counterclockwise direction. To allow otherwise will damage the chamber. Use a clean rag to wipe the reamer clean of any metal chips; also, blowout the chamber with compressed air before taking another cut. This procedure is repeated until the reamer is nearly "home" by about 0.02 in. Leave this much space until the receiver is fitted, to allow for headspace correction.

If the barrel has not been threaded prior to chambering, leave the barrel in its present position and thread as discussed earlier in this course. The thread of the barrel should fit the receiver without any loss of motion, and the barrel should screw up by hand to within about ¼ in. on the circumference of its position when fully home.

Remove the barrel from the lathe bed and tighten the barrel onto the rifle receiver with one of the several types of barrel vises available on the market. Or, if you have a bench vise of sufficient size, merely bore out a set of oak blocks to grasp the barrel. Then, coat the barrel with powdered rosin and tightly clamp it between the two wood blocks in the bench vise. A suitable wrench is then used on the receiver to tighten it onto the barrel; the type will vary, depending upon what type of receiver is used.

HEADSPACE

Next comes *headspace*: the correct distance between the head of the cartridge in the chamber and the face of the bolt or breechblock. The headspace should be such that when a cartridge of maximum dimensions is positioned into the chamber, the bolt will close without effort and have almost a friction contact with the head of the cartridge case. Figure 14 shows the dimensions of a rifle chamber for the .30-06 cartridge.

Headspace gauges are available to determine the proper dimensions, and are designated "Go," "No-Go," and "Field." In most cases, you should have both Go and No-Go gauges.

Secure the barreled receiver into a padded bench vise, with the muzzle pointing toward the floor. Clean the chamber thoroughly of all oil and metal chips, and then place the Go gauge into the chamber. Insert the action bolt and try

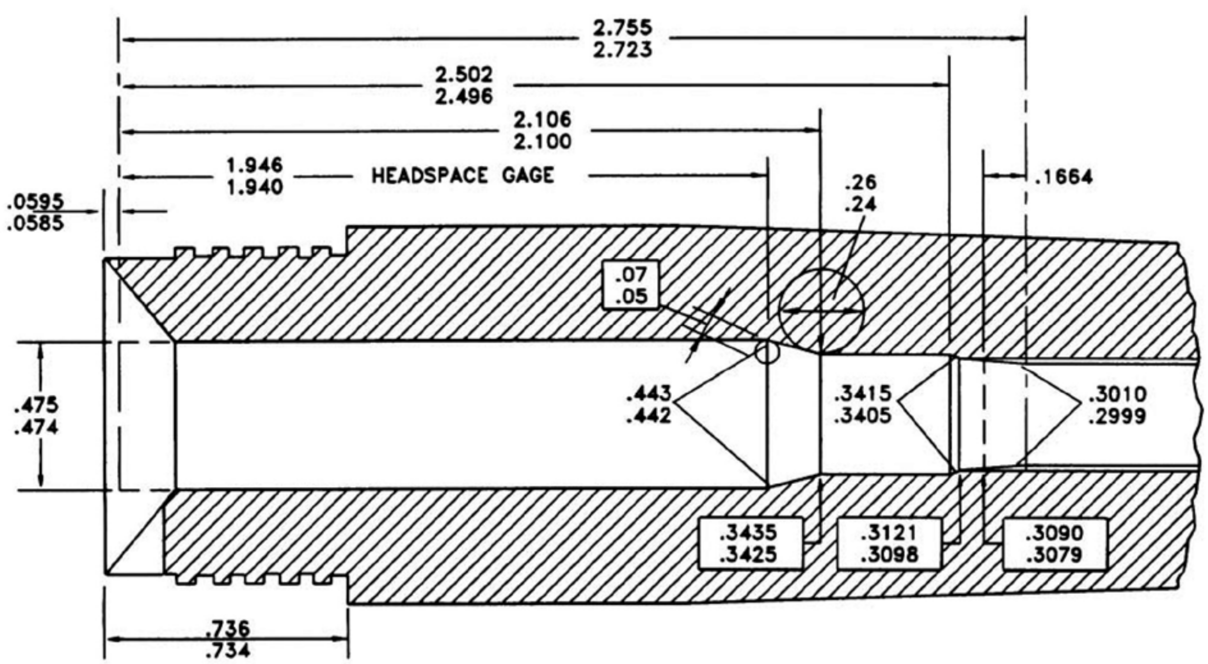

Figure 14: *Dimensions in inches of a rifle chamber for the .30-06 cartridge.*

closing it. It will probably not close completely because the chamber was purposely left about 0.02 in. too short when the finishing reamer was removed. If this is the case, use an extension handle on the chambering reamer (to get through the receiver and into the chamber area of the barrel), and gently insert the reamer into the chamber. Next, use a tap wrench on the chambering reamer extension handle, use cutting oil on the reamer, and take one light cut (one revolution). Remove the entire chambering assembly, wipe both the chamber and reamer clean, and again try the Go gauge. Continue this operation of taking one light cut and trying the Go gauge until finally the bolt will close tightly on the Go gauge.

Now, use a polishing cloth, such as 500-grit abrasive paper, positioned into a split end of a wooden dowel, which, in turn, is chucked into a fast electric drill (or lathe). This is used to polish the chamber just enough to be bright and free of all tool marks.

.308 headspace gauges.

Try the Go gauge once more. The bolt should close snugly, without much effort. If you think too much effort is required, go back to the reamer. Take one more light cut, then polish. To be sure the job has been correctly done, use the No-Go gauge as a check. The bolt should not close on this gauge; if it does, great force should have to be applied to do so.

Once you get some practice and are confident about taking accurate measurements, the time involved can be cut considerably by taking measurements prior to chambering the barrel. A good machinist or gunsmith can leave out this trial-and-error method just described and usually produce an accurate cut right on the lathe.

To complete the chambering while the barrel is still chucked in the lathe, first use a depth micrometer. Holding the micrometer flush across the front ring of the receiver, measure down to the inside of the front shoulder, where the end of the barrel will terminate. Take another measurement, with the stripped bolt in place (locked in its closed position), from the front right of the receiver to the bolt face. The second measurement, minus the first measurement, minus about 0.002 in. for a crush factor, is the distance the headspace gauge must protrude from the chamber breech to rest against the bolt face. With these measurements, many gunsmiths are able to obtain a perfect chambering job on the first time around, but it takes a little practice to perfect.

Free Boring

A rifle with excessive headspace of between 0.035 in. and 0.040 in. gains from 75 to 100 feet per second velocity, depending on the cartridge. The reason for this increase in velocity is that this increased headspace gives the bullet a little space to travel before it strikes the lands and grooves (rifling) of the barrel. A bullet will enter into the rifling faster with this slight running start, so to speak, than from a standing start with the bullet already touching the rifling at the time of firing. But excessive headspace can also be dangerous.

Knowing the above facts, the late Roy Weatherby started experimenting with his now-famous line of Weatherby Magnum cartridges during the 1940s. Rather than allowing excessive headspace to give the bullets a running start, he cut out the lands and grooves of the rifling just ahead of the bullet seat for about ¾ in. This practice is called *free boring*. Theoretically, free boring gives the powder gas more area to expand before the bullet encounters resistance; this reduces chamber pressure and allows for more powder in the charge, which supposedly increases the bullet's velocity.

A cross-section of the Weatherby Mark V action and attached barrel is shown in Figure 15. In reviewing this illustration, note the distance from the nose of the bullet to the beginning of the rifling in the bore. This is the *throat*, or *free bore*.

Actually, the amount of free bore in Weatherby rifles has varied over the years. The original length of free bore used in Weatherby rifles for their Magnum cartridges was approximately ¾ in. Then between 1967 and 1968, Weatherby shortened this length to 7⁄16 in. Therefore, those who use reloading data must be aware that the shorter the free bore, the higher the resulting pressures when the cartridge is fired. In other words, the loads must be reduced accordingly.

Experts still argue about which is best — free bore or non-free bore. Some shooters will have nothing else but free bore, while others claim that free boring a rifle is a waste of time and money. Regardless of who might be right, gunsmiths get lots of calls for free boring, and you should know how to do it if you are called upon.

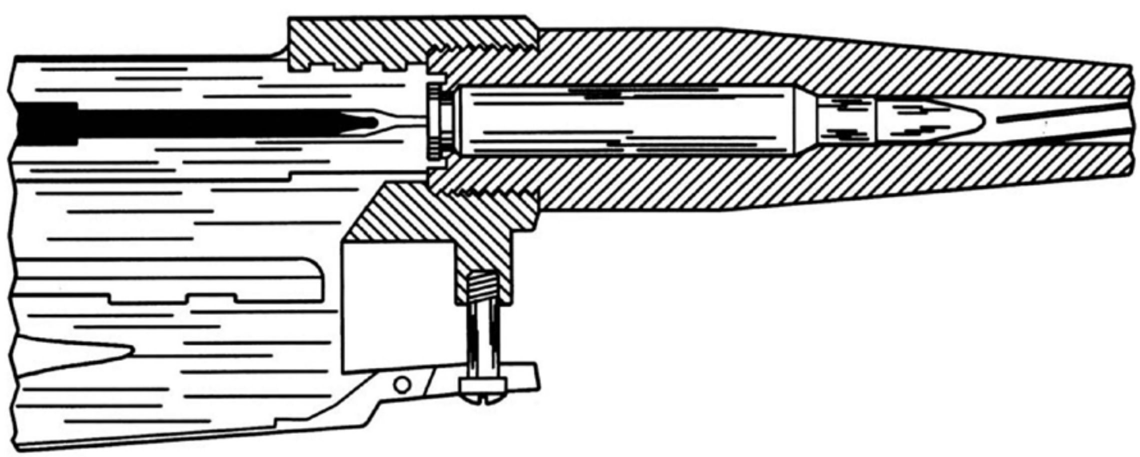

Figure 15: *Cross-section of a Weatherby Mark V rifle action. Weatherby barrels chambered for their Magnum cartridges were originally free-bored for about ¾ in., but changed to 7⁄16 in. between 1967 and 1968.*

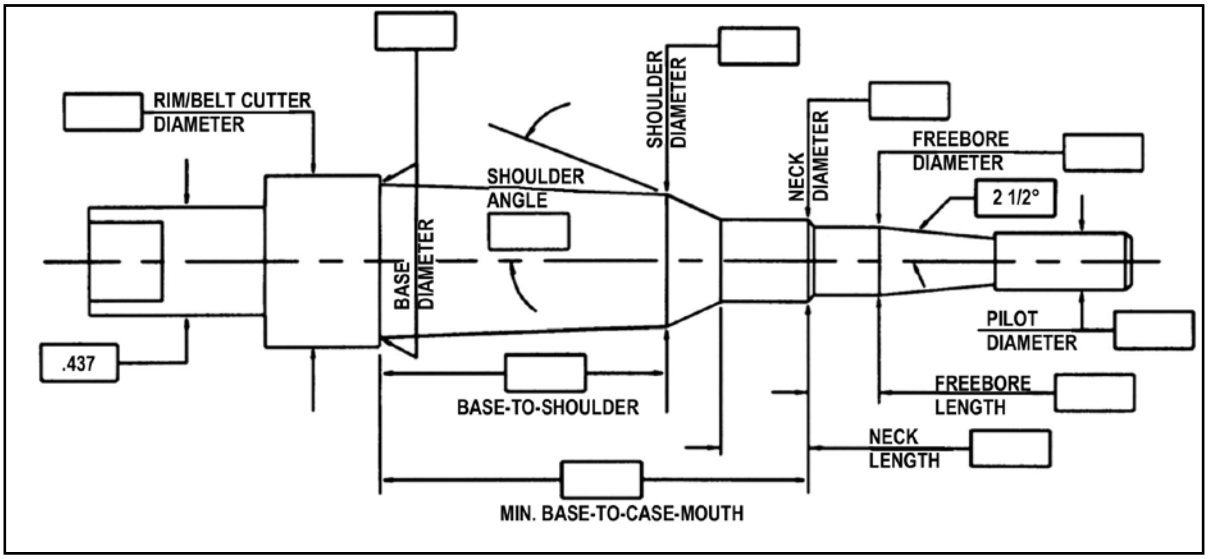

Figure 16: *Clymer chart for custom designing chambering reamers.*

If you are chambering a barrel blank for a cartridge that the customer wants free bored, you can purchase reamers so that the free boring takes place at the same time the chamber is cut. Clymer Manufacturing Co., Inc. furnishes chambering reamers with long throats. If your customer specifies a nonstandard length of free bore, Clymer will even make a custom reamer for you. The chart in Figure 16 shows a typical bottleneck cartridge with boxes for filling in the dimensions you desire. Note the box designated "Free bore length." If you want a free bore reamer for a standard cartridge, all you have to do is fill in the amount of free bore, and specify "standard dimensions" for the remaining boxes.

Clymer also furnishes reamers for barrels that are already chambered for a certain cartridge. *Throaters*, sometimes called *free bore reamers,* are used to extend the throat of a chamber in order to give more clearance around the bullet. Some gunsmiths will also order chambering reamers with a throat section and will then use a separate throater to cut the throat of the chamber to match a specific bullet.

The standard throaters supplied by Clymer are generally 0.002 in. larger than the actual bullet diameter. Therefore, if 0.308 in. diameter bullets are used, the throat will be 0.310 in. Two throat angles are also available as standard: 1°30' and 2½°.

All Clymer throaters have five left-hand spiral flutes to prevent the flutes from dropping into the rifling and to give a superior surface finish. The tool is 4 in. long with a ¼ in. shank diameter to fit their throater T-handles.

Free boring is done almost exactly the same as described earlier in this lesson in the section titled "Chambering". If the barrel has already been chambered, you can lengthen the throat of the chamber without any power tools. Merely purchase the proper throater, attach a throater T-handle to reach through the receiver to the chamber, and cut the throat by hand. A pilot on the end of the throater helps to align the tool with the bore.

Shotgun Chokes

A choke is a constriction at the muzzle of a shotgun barrel that causes the charge of shot to hold together in a dense string. Most shotgun barrels are constricted to some degree. True cylinder bores (no choke) are confined to riot or "deer" shotguns, which have barrels made especially for shooting rifled slugs and buckshot.

The shotgun choke was invented by Frenchman Henri Pellet in the city of Liege, Belgium, in 1861. His original choked barrel was almost identical to the Belgium choke, which is used by most of the better shotgun makers today— including Fabrique Nationale, the plant that made Browning shotguns in Liege, Belgium.

An American named Fred Kimble is sometimes credited with the invention of the shotgun choke, but this is disputed among experts. Regardless of who invented the choke, it was a good idea and made shotguns much more effective than they were previously.

The Belgium choke is also known as the *English-style choke* because the English were quick to adapt the choke. With this choking system, the bore tapers to a parallel section known as the "resserre" or "lede." However, the choke itself is the cone behind the parallel lede.

The *straight taper choke* is said to have originated in Germany and is the type used on better-grade U.S. shotguns. A special choking reamer is used with the required taper to produce this choke.

The *swaged choke* is used on most inexpensive single-barrel shotguns. A long taper is normally used to prevent the metal from crimping in the forming die.

A *bulged, convex,* or *"jug" choke* is still utilized to some degree, especially in rechoking operations where integral choke tubes are not wanted.

The *reverse,* or *bell, choke* (sometimes called a *"skeet" choke*) is used for making a very wide pattern. It is good for short-range shooting only.

All of the choke types described above are shown in Figure 1.

Any modification of existing chokes should be done with care. This is normally a trial-and-error practice in which you pattern the gun after each trial until the desired choke pattern is obtained. Shotguns are patterned by shooting at a large square of paper. The standard distance is 40 yd. from the muzzle. A black bullseye or square is used as an aiming point.

After shooting, the target is inspected, and a circle with a 30 in. diameter is then drawn to take in the greatest number of shot holes. This is done without reference to the bullseye, which

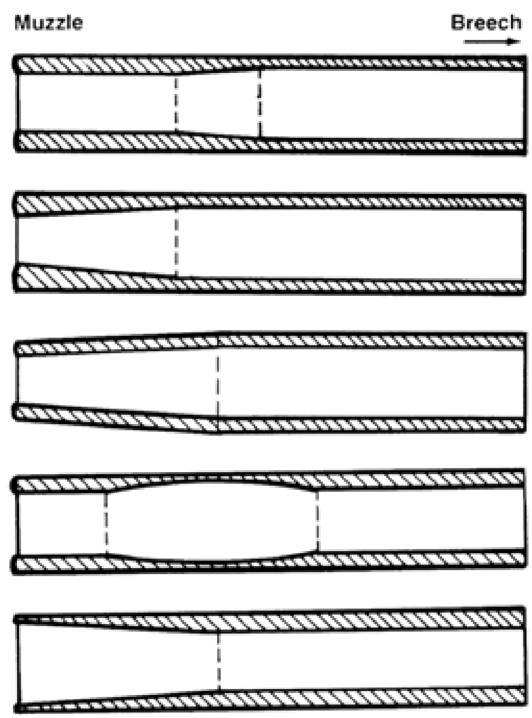

Figure 1: *Several types of chokes may be found on both American and foreign shotguns. From top to bottom: Belgium, or English-style, choke; German, or straight-taper, choke; swaged choke; convex choke; and the reversed, or bell, choke.*

may or may not be in the center of the resulting circle. The shot holes in the circle are then counted and compared to the number of shots known to be in identical shotshells having the same shot size and weight of shot.

Chokes are made to certain restrictions to produce the following results:

- Full Choke: 65% minimum of charge in a 30 in. circle at 40 yd.
- Improved Modified Choke: 60%-70% of shot charge in a 30 in. circle at 40 yd.
- Modified Choke: 50%-60% of shot charge in a 30 in. circle at 40 yd.
- Improved Cylinder Choke: 35%-50% of shot charge in a 30 in. circle at 40 yd.
- Cylinder Bore: 25%-35% of shot charge in a 30 in. circle at 40 yd.

SCREW-IN SHOTGUN CHOKES

The screw-in shotgun choke tube is the standard for shotgun manufacturers all over the world. It allows the industry to inventory fewer barrels and shotguns, while providing the consumer with a practical, more versatile shotgun at a very low cost. However, most gun manufacturers will not refit the guns that are already in the field. Many gun owners would like to convert their favorite shotgun into a more modern, versatile choking system. Choke tube installation is in demand all over the country, and the return on your investment in tooling will be great.

The installation of choke tubes can be done with minimal equipment. In fact, if you do any gun work at all, you probably already have most of the necessary tools. In addition to the installation tool kit, you will need the following:

- A bench vise with rotating base and padded vise jaws
- A 1 in. micrometer, vernier caliper, or barrel gauge
- A method of turning the tooling (bit and brace or power tools)
- Cutting oil
- Honing oil and a barrel hone
- A shotgun cleaning kit

Step 1: Cleaning. Open the action and make sure the gun is unloaded. Remove the barrel from the action and clean and deburr it thoroughly. Be sure to remove any leading and plastic from the bore.

Step 2: Outside Barrel Diameter. Measure the outside diameter of the barrel at the muzzle to determine if the barrel meets the minimum outside dimensions for the size tube to be installed. Refer to the specification chart in Figure 2. The abbreviation "O.D." stands for "outside diameter," and "I.D." stands for "inside diameter." Figure 3 shows where to take these measurements.

Step 3: Bore Diameter. Measure the inside of the bore behind the existing choke to be sure that the bore is not oversized. This can be accomplished by starting with a blank, unsized pilot and inserting it from the breech end of the barrel. If it drops through the barrel easily, the bore is oversized and the barrel cannot be fitted with choke tubes. This problem is most likely to arise with the so-called slug and riot gun barrels.

Step 4: Concentricity. This area of installation is where you can get into the most trouble. A lot of older gun barrels have bores that are not concentric with the outside of the barrels. Avoid

Figure 1a: Screw-in shotgun choke.

Barrel Specification Chart			
Gauge	**Thread Size**	**Min.O.D.**	**Max. I.D.**
10 gauge	0.865 x 44 DL	0.900	0.781
12 gauge	0.795 x 44 DL	0.825	0.746
12 gauge, thin	0.774 x 44 DL	0.805	0.730
20 gauge	0.675 x 44 DL	0.700	0.626

Figure 2: *Specification chart showing the various dimensions of shotgun barrels for integral choke installations.*

attempting this work on guns that are close to the minimum diameter and have had their barrels shortened to install Cutts Compensators. A lot of the older Model 12 Winchesters and Model 37 Ithacas, made before World War II, are not as concentric as later, more modern barrels.

Example 1: A 12-gauge barrel has a 0.834 in. outside diameter; wall thickness varies 0.004 in. divided by 2 equals 0.002 in. When this amount is subtracted from the original dimension, the adjusted outside diameter becomes 0.832 in. This dimension is larger than the minimum of 0.825 in., so an internal choke tube can be safely installed on this barrel.

Example 2: A 20-gauge barrel has a 0.701 in. outside diameter; wall thickness varies 0.006 in. divided by 2 equals 0.003 in. This amount subtracted from 0.701 in. becomes 0.698 in. Since this dimension is 0.002 in. smaller than the minimum of 0.700 in., this barrel cannot be fitted with an internal choke tube.

Chrome-lined barrels require special attention. The first step is to remove the chrome from the front edge of the barrel. This is accomplished by placing a piece of 240-grit emery cloth on a flat piece of steel and sanding off the chrome, taking care not to round the corners. A good method to check for any remaining chrome is to use instant cold blue. This will blue the exposed steel and show any remaining chrome. The next step is to remove any remaining chrome from the bore. This can be done with a barrel hone. Insert the hone to a depth of about 3 in. and hone back and forth to the muzzle until all chrome is removed. Repeat step one, since any remaining grit from the hone will dull the choke reamer rapidly.

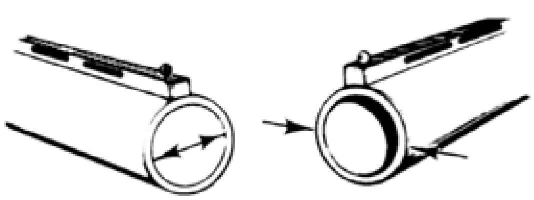

Figure 3: *Areas for measuring the dimensions of shotgun barrels. The drawing on the left is where the inside diameter is measured; the drawing on the right is where the outside diameter is measured.*

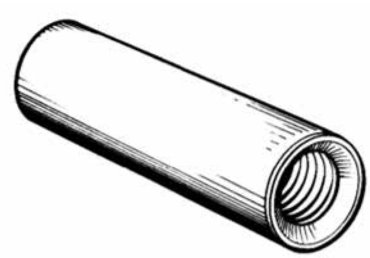

Figure 4: *Typical solid pilot with threaded pilot seat.*

Figure 5: *Barrel-seating spacer. Slide this over the reamer until it stops on the largest diameter of the reamer.*

Figure 6: *Typical choke tube reamer.*

Step 5: Select a tight-fitting pilot from the kit. Pilots are graduated in 0.002 in. increments. The pilot selected should fit snugly in the bore with no wobble, yet turn freely. The next largest pilot should not fit into the bore. It is important that the proper size pilot is selected, since one too small will allow the reamer to cut out of line with the bore, causing the point of impact to change. Push the pilot from the chamber end of the barrel towards the muzzle with the threaded seating end of the pilot, shown in Figure 4, facing the muzzle. The pilot will stop when it reaches the existing choke.

Step 6: Slide the barrel seating spacer, shown in Figure 5, over the reamer until it stops on the largest diameter of the reamer. Carefully screw the end of the reamer into the pilot through the existing choke. Be sure to keep the seating surfaces of the pilot and reamer clean and free of chips, burrs, etc. You are now ready to attach the reamer to its drive source. Many installers use hand tools, such as a bit brace of the B-Square Choke Tool installing jig (adapter available from Colonial Arms), while larger, well-equipped shops may choose to do the reaming operation with power tools. Whichever method you choose to use, the reamer must be kept clear of chips and well-lubricated with a good cutting oil at all times.

Step 7: You are now ready to start the reaming operation. With the barrel secured to prevent slippage and damage to the rib, brush a little cutting oil on the reamer (Figure 6) and squirt a little cutting oil into the bore. Start turning the reamer in a clockwise direction. Never reverse a reamer; this may permanently damage the tool. Cut the barrel about ⅛ in. deep and withdraw the reamer while still turning. Remove chips and lubricate again. Continue this until the reamer stops cutting and rubs on the barrel seating spacer. You can now remove the reamer and pilot from the muzzle end of the barrel and clean the bore to prepare for the next step.

Step 8: This step involves threading the barrel to accept the choke tube. Remove the bore pilot and barrel seating spacer from the reamer and install the pilot on the tap. Slide the assembly into the bore, lubricate, and slowly start the tap, taking care to keep the tap well lubricated at all times. The tap will cut fairly easily until it bottoms out on the seating surface (approximately 17 complete turns). Do not force the tap beyond this point. The tap is capable of removing the seating surface if enough pressure is applied. After tapping, reverse the tap and carefully remove the tap and pilot from the barrel.

Step 9: Remove the tap from the pilot. Clean and attach the pilot to the reamer. With the barrel seating spacer now removed from the reamer and the barrel cleaned, you now can make the final reaming cut. To clean up the seating surface, lubricate the reamer and cut until the reamer stops cutting and rubs on the largest diameter of the reamer.

Step 10: Clean out all chips, oil, etc. with a bore brush and a good-quality solvent. Or, you may choose to use a thread-cleaning tool (Figure 7). When using the thread-cleaning tool, apply a little petroleum jelly to the grooved section of the tool and screw it into the barrel until it stops. Remove the tool from the barrel and wash off the petroleum jelly (which now contains the trapped chips, dirt, etc.) in hot water or shop solvent. Now that the barrel is clean, install an improved cylinder tube. The tube should screw in smoothly and fit flush with the end of the barrel when the tube stops turning. With the tube properly seated, visually check the seating surface with a flashlight. You should see the seating edge of the tube resting squarely against the slightly smaller bore size. If the area directly in front of the tube is roughly finished, you will now have to hone this area. This can be accomplished with a barrel hone and a small electric hand drill. After honing, remove the tube and clean the barrel thoroughly. Select the choke tubes to be supplied to the customer; install every one and visually check the seating. Test fire the gun.

Figure 7: *Barrel thread-cleaning tool.*

PRECAUTIONARY MEASURES

- Never turn the reamer in reverse direction.
- Use shop tags that have warnings for choke use and can be left on the barrel for the consumer.
- Never ship a barrel that has been machined for choke tubes without a choke tube being in place to support the thin section.
- Be cautious when working with Belgium Browning over/under shotguns; there may not be enough metal between the barrels, even though the measurements indicate otherwise.
- Choke tube lube is not only a grease, but also it has metal particles to support threads. This is good when using tight chokes such as an extra-full one. It prevents the tubes from becoming stuck in the barrel.

ADJUSTING EXISTING CHOKES

Most shotguns made in the last 90 years could use some choke work. Many of these are inexpensive single-shot, break-open type shotguns where the cost of installing an integral choke tube is not warranted; few people want to invest $150 for an integral choke installation on a $100 gun. You will have two basic adjustments to make. One is to open up the choke from full to improved modified. The other is to put some choke in a barrel that has been cut off, leaving it with a cylinder bore.

The majority of single-shot shotguns manufactured in the United States contain full chokes. A full choke is fine for certain shooting beyond 30 yd. , but for closer shots — for example, 15-25 yd. — the shooter might as well use a rifle; the shot pattern is just too tight for consistent hits. Therefore, owners of these single-shot guns can improve their shooting by opening up the choke a little bit.

Actually, the opening up of a shotgun choke to a slightly larger diameter is a relatively simple matter if you have the proper tools. The procedure requires nothing more than the controlled removal of a bit of metal from the forward bore of the shotgun barrel. However, to obtain a good shot pattern at a given yardage requires a number of additional considerations, all of them equally important to the end result and the customer's satisfaction with your workmanship.

CHOKE REAMERS

The bore hone and four adjustable reamers shown in Figure 8 will cover most choking requirements for any shotgun from a cylinder bore in 12-gauge to a full choke in 28-gauge. Each reamer is equipped with angle blades to provide a perfectly flat slicing cut at all diameters to eliminate chatter. The blades remain absolutely true at all size adjustments and do not bulge or curve, thus assuring proper bore configuration. The factory maximum/minimum specifications of each reamer are shown in Figure 9.

As with all reamers, the cutting edge of an angle-blade expanding reamer should be honed lightly before each choking operation for best performance. Arkansas stones and thin India stones should be used for sharpening. Reamers are fine service tools and should not be abused. Never throw them in with other tools. Keep them oiled and individually wrapped when not in use. If metal chips accumulate between the cutting blades, never try to knock them out by hitting the tool against the edge of a bench or on a block of wood. The correct way to remove these chips is to brush them out carefully. Also, always release the tension on your angle-blade reamers when they are not being used.

When using a reamer, never back it off the job. Always keep it turning in the same direction until the reamer is removed from the barrel. Most beginners try to get the job done quickly, taking big cuts at one time. Never take more than a 0.003 in. cut at one time—preferably less. In cold weather, angle-blade reamers should be slightly warmed before exerting extreme setting pressure to prevent possible fracture of the blades.

Figure 8: *The bore hone and angle-blade expanding reamer shown above will handle any choke requirements that you may encounter.*

Shotgun Gauge	Fractional Dimensions	Decimal Dimensions
12-gauge	23/32 - 25/32	0.71875-0.78125
16-gauge	21/32 - 23/32	0.65625-0.71875
20-gauge	19/32 - 21/32	0.59375- 0.65625
28-gauge	17/32 - 19/32	0.53125- 0.59375

Figure 9: *Maximum/minimum dimensions of angle-blade expansion reamers.*

BORE AND CHOKE DIMENSIONS

Actual bore and choke dimensions vary from one manufacturer to another and sometimes even from barrel to barrel of the same model. Measurements of each barrel should be made with a bore micrometer or choke calipers. The bore diameters and amount of constriction for each choke listed in the chart in Figure 10 is an average, using the American standard, but should be used as a guide only.

When referring to the chart in Figure 10, remember that the differences between the various choke diameters is overall diameter difference. For example, if a customer wants a 12-gauge full choke opened up to a modified choke, the difference in constriction between the two chokes is 0.016 in., obtained by subtracting the modified choke dimension (0.019 in.) from the full choke dimension (0.035 in.); that is, 0.035 - 0.019 = 0.016 in. This is the difference in diameter, but the actual amount of metal to be removed at the circumference is half this amount, or only 0.008 in. Always remember this, because if you were to make the full 0.016 in. cut (or a series of cuts totaling 0.016 in.), you would increase the inside diameter by double, or by 0.032 in. Use the following equation to calculate the amount of metal to remove:

$$\text{Amount of metal to be removed} = \frac{\text{Larger diameter} - \text{smaller diameter}}{2}$$

Since bore diameters vary so much, measuring instruments within a plus-minus of 0.002 in. is sufficient for choke work. The Brownells choke calipers, shown in Figure 11, used in conjunction with an accurate micrometer, are ideal for measuring the amount of choke change during choke modifications. To use the calipers, secure

Gauge	Bore Diameter	Amount of Constriction						
		Full	Imp. Mod	Mod.	Skt-2	Imp Cyl.	Skt-1	Cyl.
12	0.729	0.035	0.025	0.019	0.012	0.009	0.005	0.000
16	0.667	0.028	0.020	0.015	0.010	0.007	0.004	0.000
20	0.617	0.025	0.019	0.014	0.009	0.006	0.004	0.000
28	0.550	0.022	0.016	0.012	0.007	0.005	0.003	0.000

Figure 10: *Bore and choke dimensions.*

Figure 11: *Brownells choke comparison calipers.*

the barrel in a bench vise and insert one end of the calipers into the shotgun bore. Loosen the T-handle screw and expand the calipers to a "touch fit" and locate the maximum choke dimension. Then lock the T-handle and carefully measure the protruding comparison end of the calipers with a micrometer. Next, measure the cylinder bore of the gun. Subtract the two measurements and refer to the chart in Figure 10. This will give you the approximate choke of the gun for a certain gauge.

PERFORMING CHOKE ADJUSTMENT

Before altering a shotgun choke, the barrel should be removed from the action. However, if this is not possible, remove all the action parts. Another alternative is to plug the chamber adequately so that metal shavings do not fall into the action during the choking process. Then, thoroughly clean out the bore before removing the chamber plug.

Assuming that you have already taken measurements of the shotgun bore and existing choke as discussed previously, secure the barrel in a padded vise in a vertical position with the muzzle pointing upward and approximately waist-high, as shown in Figure 12. You do not want to cut the choke with the barrel in a horizontal position because more metal will be removed from the bottom of the barrel due to the weight of the reamer.

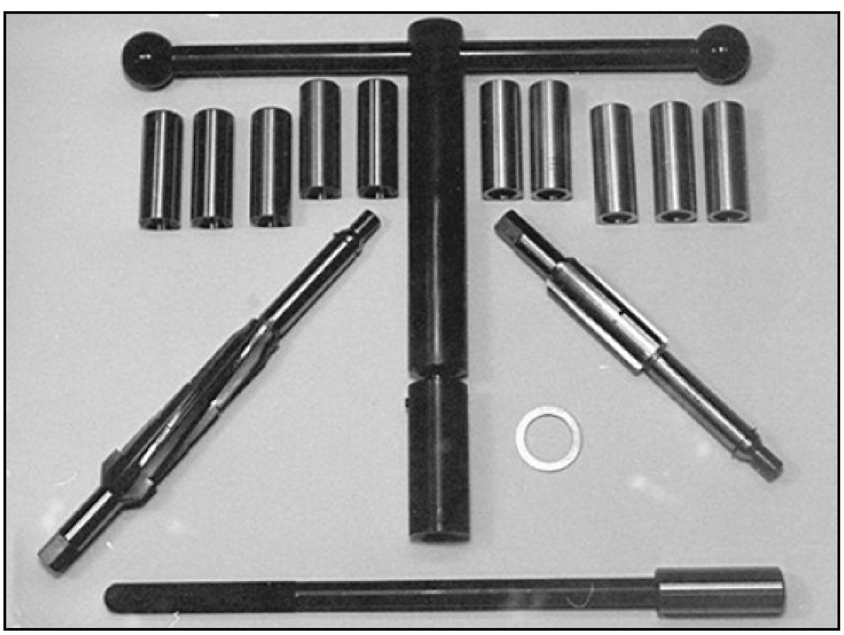

Figure 12: *A Colonial maximum bore gauge can be used in multiple calibers and without the need for a metal turning lathe.*

In addition to the angle-blade expanding reamer, you will need the following:

- Large tap wrench to hold the reamer
- Dark cutting oil
- Cleaning rod
- Cleaning patches

A small can or bucket on the floor under the barrel will catch the excess oil and used patches.

Select the appropriate reamer, adjusted to its minimum diameter, and try it in the muzzle of the shotgun barrel. If it goes all the way in without touching the sides, remove it and adjust for a larger diameter. This adjustment is made by backing off the rear adjusting nut a half-turn maximum and tightening the front adjusting nut. The operation pushes the blades to the rear and up the inclined cuts to enlarge the overall diameter of the reamer. The reamer is tapered with the small end at the front to guide the reamer for correct alignment with the bore and choke.

Continue adjusting the reamer a small amount at a time until it just touches the sides of the choke. Apply the cutting oil and make the first cut by rotating the reamer in a clockwise direction, allowing the weight of the reamer and wrench to apply the pressure. When the reamer has cut its full length, continue rotating it in the same direction and withdraw it from the barrel. Do not reverse the direction of rotation or withdraw the reamer without the clockwise rotation or the choke will be scored. Once you remove the reamer, brush the chips from the reamer and clean the barrel with a tight patch. Measure the choke and repeat the procedure if additional metal must be removed. Test fire for shot patterns, especially if your customer has specified a particular percentage at a given yardage.

There is a flat on the adjusting nuts that can be used as a scale during the choking operation. Position this flat between two of the blades and make a cut. Now remove the reamer and rotate the nut to a position between the next two blades. The second cut will remove 0.002 in. from the choke diameter.

The final 0.001 in. of metal should be removed with the barrel hone. This is nothing more than a cylinder hone that has been used in the automotive trade for years. The honing stones are attached to flexible "fingers" that should be pressed against the sides of the choke by the coil spring, and the pressure should be firm at all times to prevent chatter. The flexible shaft ensures correct alignment with the bore. The hone can be rotated in several ways, but a conventional, electric hand drill will work well. Insert the hone in the choke and turn on the drill. Move the hone in and out for about 15 seconds with plenty of cutting oil in the barrel. Always turn the drill off before removing the hone from the barrel. Once removed, wipe the bore clean and inspect it. The barrel should be smooth and free of all scratches.

CHROME-LINED BARRELS

Angle-blade expanding reamers will not cut chrome lining, and any attempt to do so will ruin the reamer and void the guarantee. To determine if a barrel is chrome-lined, touch a drop of instant cold blue to the inside of the muzzle. If the metal blues or stains, it is not chrome-lined, and you may proceed as usual.

In some cases, the chrome lining can be removed by careful honing and flooding with cutting oil prior to the normal choke adjustment. However, this can be a tricky operation, depending upon the thickness, uniformity, and hardness of the chrome, and should be undertaken with caution.

REVERSE, OR JUG, CHOKES

Reverse, or *jug*, chokes, shown in Figure 13, are found in some shotguns. The choke effect is obtained in reverse choking by the removal of metal from the bore starting a short distance behind the muzzle and extending down the barrel toward the breech. On a 12-gauge shotgun, for example, the recess may be from 10 in. to 12 in. long and about 0.015 in. deep for modified choke and 0.021 in. deep for full choke. You cannot open up a choke such as this by making the recess deeper. Doing so would tighten the choke. Opening the pattern on such a gun can only be achieved by very carefully honing the short stretch of barrel between the muzzle and the choke recess.

Know how a reverse choke operates, as you may be called upon to tighten the shot pattern on such a choke. Then, removing metal will do the job for you.

In either case, repeated test firings should be made during this type of adjustment to be sure too much metal is not removed and the pattern is not opened or closed too much.

TIGHTENING CHOKES

We have talked much about opening chokes in shotguns, but what about tightening them, obtaining a closer shot pattern for those long shots?

There are many reasons why you may be called upon as a gunsmith to tighten shotgun chokes. There are thousands of shotgun barrels with split or otherwise damaged muzzles. The only way to correct these defects is to cut the barrel back a few inches at the muzzle. However, in doing so, all choke is removed, leaving a cylinder bore. Perhaps the owner of an older shotgun has had an adjustable choke attachment installed sometime in the past and now finds the bulky attachment undesirable. He or she wants the attachment removed and a conventional choke installed in the plain barrel. Another reason may be to gain shot range. The average full-choked shotgun will hold a killing pattern to about 40-50 yd. But in some areas, shots at waterfowl — particularly wild geese — extend out to 60 or 70 yd. To obtain a suitable shot pattern at these ranges requires a tighter choke than is normally found on factory shotguns. Here's where a tighter choke comes in handy.

In some areas of the United States, shotgun shooting matches are big business. Competitors try to knock the center out of a cardboard target marked with an X. These shots are fired at ranges from 27 to 31 yd., depending upon the match. In these matches, shooters want the absolute tightest shot pattern possible.

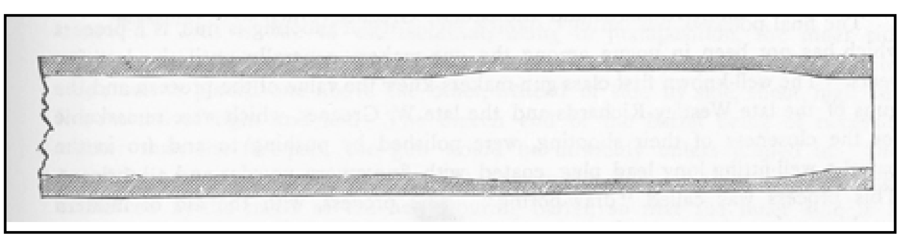

Figure 13: *A jug choke consists of a recessed area within the shotgun bore.*

Figure 14: *Back-boring bar.*

There are several ways to make a shotgun shoot tighter patterns. Substituting copper-plated shot instead of the conventional lead shot will usually tighten the shot pattern from ½ to 1 choke degree. The plastic wad columns in shotshells will do the same thing. However, the other methods involve some type of choke adjustment to the shotgun barrel.

BACK-BORING

Back-boring is the process of removing metal from the bore of a shotgun barrel from directly in front of the chamber, the full length of the barrel, to about 1 in. behind the muzzle. The process increases the bore diameter to a size larger than the muzzle diameter; thus, a choke to some degree is installed in the barrel by the process. The last inch of the barrel tapers down to the original size of the muzzle.

Back-boring is done with a special reamer, with the reamer's end tapered to cut the desired choke in the barrel. Such reamers are available from various manufacturers. However, the process is very slow with just one reamer. It is best to have several reamers in 0.002 in. increments. For example, if you wish to remove 0.006 in. metal from the bore of the barrel, you would use three different sizes of reamers, starting with the smallest diameter and ending with the largest diameter.

Back-boring reamers are also a good way to restore the bore of a pitted shotgun barrel. This will be described in a later lesson.

SLEEVING

Sleeving shotgun barrels is another way to obtain a tighter choke. In general, sleeving involves installing a piece of barrel onto the original barrel. The operation requires the use of a metal-turning lathe.

A choked sleeve is about 6 in. long. One end of this sleeve must exactly match the bore diameter of the original barrel; the bore in the sleeve will then be tapered down to a smaller diameter at the muzzle (opposite end) to obtain the desired choke.

First, about an inch of the original barrel is turned down on the lathe a few thousandths of an inch to accept the sleeve. This same distance is then turned on the inside of the sleeve to obtain a perfect fit and to ensure that the bores of each piece align perfectly. The sleeve is then silver soldered onto the original barrel. Many shooting match guns have been sleeved this way to obtain very tight shot patterns at 30 yd.

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Shotgun Chambers

Over the years, shotguns have had a variety of chamber lengths for the shells that were manufactured when the gun was originally built. Most shotguns manufactured before approximately 1930 had chambers less than 2.760 in. overall — the length now required to handle the overall length of modern shotshells. Because of these obsolete chambers, the already-weak chamber takes an extra beating due to the higher pressures caused by firing the longer, modern shells in these short chambers. To function properly, the shell's crimp must have room to unfold completely flat when the shot and wads go from the case to the bore. Any small amount of case forced into their path because of a short chamber will deform the shot, tear hulls, cause excessive kicking, and raise chamber pressures above normal.

Short shotgun chambers can be reamed out by hand using a special chamber reamer sold by both Clymer Manufacturing Co. and Brownells Such reamers rechamber short shotgun chambers to modern length and cut a new long forcing cone at the same time without lengthening the chamber longer than it should be. Chamber reamers are available for 12,16,20, and .410 shotgun gauges.

Detecting and lengthening short shotgun chambers is a service that you should offer all shotgun owners. You can purchase all the equipment necessary for around $300 and then charge from $50 or more per bore. Once you have gained some experience, you should be able to measure a shotgun bore and cut the new chamber in less than one hour. You can do all this without purchasing expensive power tools.

SHOTGUN CHAMBER LENGTHS

The shotgun chamber consists of three sections, as shown in Figure 15. From left to right, first there is the recess cut for the rim of the shotshell. Next is the chamber body, which is cut with a slight taper to assist in the insertion of the shotshell and provide for easy extraction after firing. The last portion of the chamber is the forcing cone; this begins where the chamber body ends and tapers down to the bore section of the shotgun barrel.

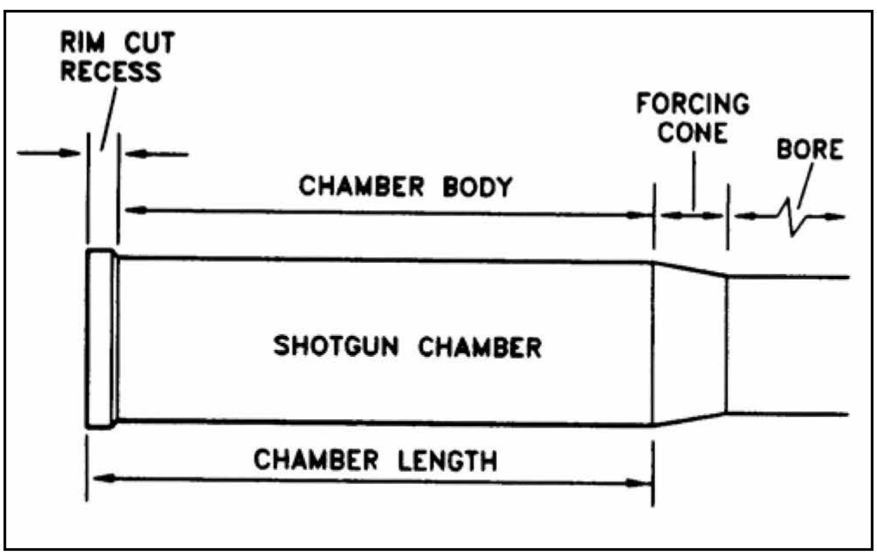

Figure 15: *Sectional view of standard shotgun chamber with standard forcing cone.*

Gauge	Chamber Length in Inches
10-gauge	2 7/8; 3 1/2
12-gauge	2; 2 1/2; 2 5/8; 2 3/4; 3
16-gauge	2 9/16; 2 3/4
20-gauge	2 1/2; 2 7/8
28-gauge	2 3/4; 2 7/8
0.410-gauge	2; 2 1/2; 3

Figure 16: *Some of the various shotgun chamber lengths used prior to 1900.*

Gauge	Chamber Length in Inches
10-gauge	3 1/2
12-gauge	2 3/4; 3
16-gauge	2 3/4
20-gauge	2 3/4; 3
28-gauge	2 3/4
.410-gauge	2 1/2; 3

Figure 17: *Current chamber length.*

When measuring shotgun chamber lengths, keep in mind that the thickness of the rim cut and the length of the chamber body are combined into one dimension. However, the length of the forcing cone is not included in the specified chamber length.

Prior to 1900, shotgun chamber lengths varied considerably among manufacturers, often resulting in odd fractions, as shown in Figure 16. After 1900, shotguns were produced in more standard chamber lengths.

From about 1920 to the mid-1930s, the gauges were standardized to the current chamber lengths that are listed in the table in Figure 17. All modern American shotguns are made in these lengths.

You will also run across metric chamber lengths and chamber diameter specifications on shotguns made in foreign countries. These chambers will differ slightly from the current American specifications, since the accepted procedure with foreign manufacturers is to carry the dimension to the nearest millimeter. The dimensions are usually stamped on the bottom of the barrel under the chamber. For example, in the marking "12-70 in. the 12 designates the gauge and the 70 designates the length of the chamber in millimeters. In this case, the 70 mm is the equivalent of the American 2¾ in. chamber. Actually, 2¾ in. is exactly 69.85 mm, but this small difference can be ignored for all practical purposes. The accepted conversion of metric chamber lengths to American standard chamber lengths is shown in Figure 18.

SHOTGUN SHELL IN RELATION TO CHAMBER LENGTH

The unfired shotgun shell is considerably shorter than the chamber length. For example, the modern star-crimped 20-gauge 2¾ in. shell is 2.43 in. in length when loaded. When fired, the crimped end unfolds and the shell is then 2.75 in. in length. This matches the chamber length of 2.75 in. Therefore, the end of the fired shell

Metric	Inches
50	1
63-64	2 1/2
65	2 9/16
70	2 3/4
73	2 7/8
76	3
89	3 1/2

Figure 18: *Conversion of metric chamber lengths to American standard chamber lengths.*

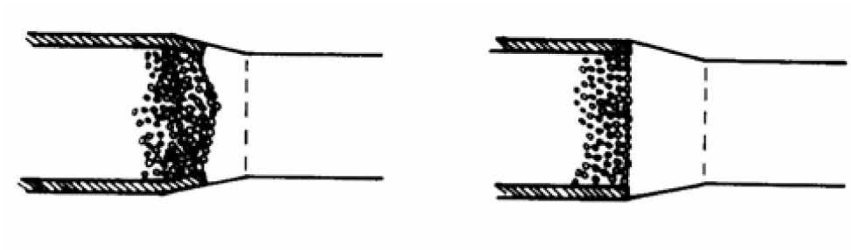

Figure 19: *"Bottleneck" effect when the end of the fired shell case enters the forcing cone, thus squeezing and deforming the shot (left), as opposed to a correct length chamber (right) in which the fired case does not enter the forcing cone.*

case stops exactly where the forcing cone begins tapering the chamber diameter down to the smaller bore diameter.

An unfired 20-gauge 3 in. shell measures 2.68 in. in length, which allows it to enter the 20-gauge 2¾ in. chamber easily (2.75 in.).

However, when the 3 in. shell is fired, the case unfolds to its full 3 in. length. The extra 0.25 in. of case body enters the forcing cone, creating a bottleneck effect through which the shot and wads must pass (Figure 19).

The amount and type of powder loaded in a shell is carefully selected to provide the correct rate of burning which provides the pressure necessary to overcome the inertia of the shot, and push it and the wads through the forcing cone, up the bore, and through the choke. This balance is absolutely essential for good patterns and the overall correct function of the shotgun. Anytime part of the fired shotgun case enters the forcing cone and creates the bottleneck effect, the balance is changed and several detrimental effects occur.

First, the momentary slowing of the shot charge by the bottleneck increases the rate of burning of the powder, which results in increased chamber pressure. This excess pressure not only puts a strain on the gun's mechanism and barrel, but also increases the amount of recoil. Provided the mechanism is capable of safely withstanding the 10% – 25% increase in chamber pressure, the gun will slowly but surely be battered to pieces.

The second effect is that as the shot is forced through the bottleneck, individual pellets become deformed and out of round. When the deformed pellets leave the barrel they will not stay with the main charge, since air pressure against the deformed pellets cause them to deflect in all directions. The end result is a poorer pattern both in percent and distribution of the pellets in the pattern circle.

While this has been an extreme example, it illustrates the necessity of the chamber length correctly matching the length of the fired shotgun shell. Anytime a portion of the fired shell case enters the forcing cone, it decreases the efficiency of the barrel and, consequently, the efficiency of the shotgun's performance.

MEASURING SHOTGUN CHAMBERS

Brownells offers a set of shotgun chamber gauges that were developed by the late Ralph Walker. These gauges are simple to use and allow you to determine the chamber length of any shotgun in short order.

To use, the shotgun chamber must be clean for accurate gauging. If normal cleaning procedures fail, make a special tool by using a brass bore brush and the forward section of a shotgun cleaning rod inserted in a ¼ in. electric hand drill. The rapid rotation of the bore brush will usually get the job done. If this fails, wrap

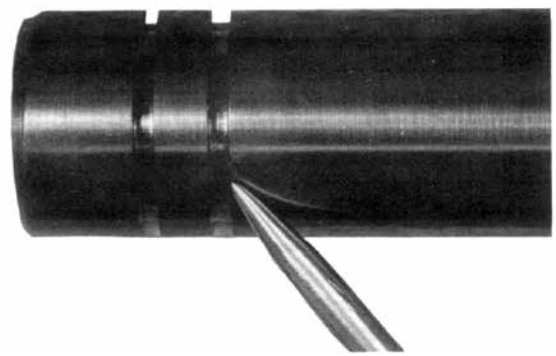

Figure 20: *Lathe-cut grooves accurately indicate chamber length when placed in a clean chamber. Forward groove measures 2¾ in. chambers; the other groove measures 3 in. chambers.*

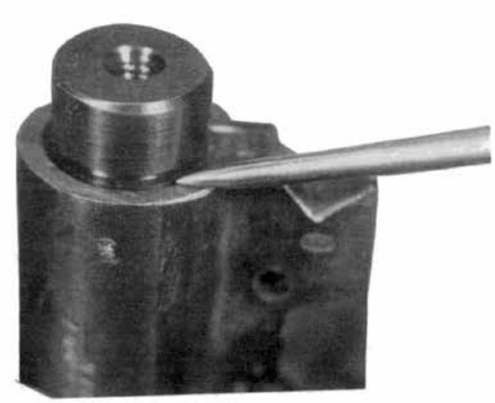

Figure 21: *Walker chamber gauge inserted into a 12-gauge 3 in. chamber, with pointer indicating that the gauge shows proper chamber depth, or length, for a 3 in. chamber.*

a small amount of 0000 steel wool around the bore brush and allow the drill to run for about a minute. Use both of these systems dry. They will remove the caked rust, powder residue, etc., and not damage the chamber. Wipe the chamber with a clean patch and use a strong light directed into the chamber to ensure cleanliness before gauging.

The Walker shotgun chamber gauges are precision-ground to specifications of each shotgun gauge chamber dimension as established by the Sporting Arms and Ammunition Manufacturers' Institute (SAAMI). The diameter of the front end is that of the chamber body where it meets the forcing cone. While a small bevel is cut on the front end to protect it, care should be exercised to prevent the edge from becoming nicked, which will produce false gauging.

The forward edge of the circular cut around the gauge body is the exact point of chamber length (Figure 20). This index edge should exactly align with the rear of the chamber rim recess cut in the barrel if the chamber length is correct. Visual observation is easy but can be made more pronounced by filling the groove with a contrasting color. A simple method is to wipe the cut clean, then with a small brush fill the groove with lacquer or shellac. Regular chalk dust sprinkled into the groove will be held in place when the lacquer or shellac dries. Another method is to use common fingernail polish.

The gauge body is not tapered to avoid false gauging on the side of the chamber. The rear end of the gauge is threaded ¼–20 tpi to accept an extension. A common ¼–20 bolt or threaded rod extension will allow easy insertion and extraction of the gauge in a chamber. After use, wipe the gauge clean and lightly oil it. Store the gauges separately. Figure 21 shows the Walker chamber gauge in use.

SHORT CHAMBERS

Starting around 1930, it became standard practice to stamp both the gauge and the chamber length on the barrel, such as "12-Gauge 2¾ in." or an abbreviation. While there are exceptions to the rule, a barrel stamped only with the gauge specifications should be checked with the chamber length gauge. Chances are that the chamber length is shorter than the current standard. It is also good practice to check metric chambers to ensure correct function with American shells.

.410-Gauge. The majority of pumps and semi-automatics will be chambered for the 3 in. shell, since Winchester pioneered this field in the 1930s with their Model 42 pump. Prior to that time the .410 was chambered in the 2½ in. length or the earlier 2 in. length. The designation .410 is somewhat misleading because it is the bore diameter expressed in hundredths of an inch and not the gauge, as measured for other shotguns. Some early single and double barrels were marked either 12 mm or 67 gauge.

28-Gauge. The original 1903 version of this shell was in 2⅞ in. chamber length but was standardized in the 1920s to the current 2¾ in. chamber length. The longer 2⅞ in. chamber will present no problems with the current 2¾ in. shell, but the condition of the gun should be carefully considered in shooting the 2¾ in. Magnum shell with 1 oz. of shot, since the earlier guns were designed for light load and ¾ oz. of shot. A few European doubles, although stamped for the 2¾ in. shell, will give extraction problems with American shells because the chambers are extremely tight, especially in the ultra-light version guns. Any that do not fully gauge 2¾ in. can be rechambered to eliminate the problem. There were a few guns chambered for a special 2½ in. 28-gauge shell, but these guns are extremely rare.

20-Gauge. Until 1926, the standard chamber length was 2½ in., and you will see a considerable number of guns with this chamber length. Provided the barrel and the gun mechanism are in good condition, these guns can be rechambered to the current 2¾ in. length. Single and double barrels require only rechambering, but the pumps and semi-automatics will usually require alterations of the feed mechanism and ejection ports in the receiver. Prior to World War I, a few double barrels and one pump were chambered for the 3 in. shell loaded with 1⅛ oz. of shot. It was not popular, but after World War II the 3 in. shell was increased to 1¼ oz. of shot and has rapidly gained in popularity. Conversion from the 2¾ in. chamber to the 3 in. chamber is usually safe in well-built guns but under no circumstance should a 2½ in. chamber be converted to the 3 in. chamber.

16-Gauge. The 2⁹⁄₁₆ in. chamber length was both the American and the European standard until 1929, when the American standard was changed to the current 2¾ in. length. The European standard did not change until after World War II, and even today the 2⁹⁄₁₆ in. (65mm) is still popular in some sections of Europe. The popularity of the gauge, the large number of guns manufactured in the United States prior to 1929, and the vast imports both before and after World War II have resulted in literally thousands of 16-gauge 2⁹⁄₁₆ in. shells. Conversion of single and double barrels to the 2¾ in. chamber seldom requires more than rechambering. Pumps and semi-automatics will require alterations of the action mechanism. While any sound gun will accept the conversion, the use of short Magnum shells should be avoided.

12-Gauge. This is without a doubt the most popular gauge in shotguns, and it also has been produced in the widest variety of chamber lengths. The British still make an ultra light

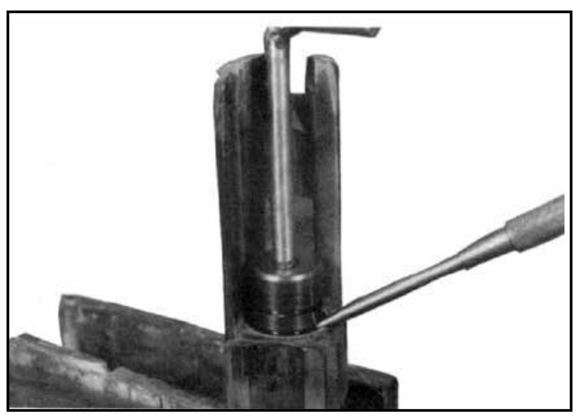

Figure 22: *The chamber gauge verifies that the chamber in the 12-gauge shotgun barrel is 2¾ in. as gauge seats to the forward ring. Note the extension handle screwed into the top of the gauge.*

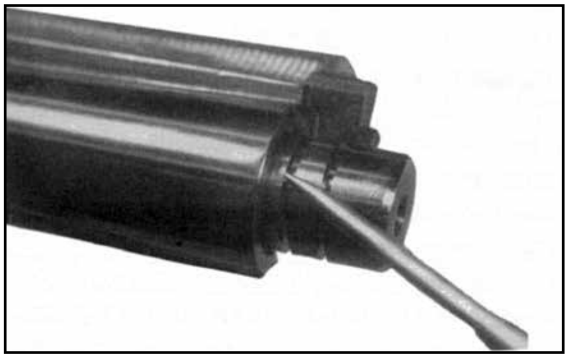

Figure 23: *Classic example of a short chamber in a double-barrel shotgun. The chamber will not accept the gauge to a full 2¾ in. depth. This particular chamber measured 2⅝".*

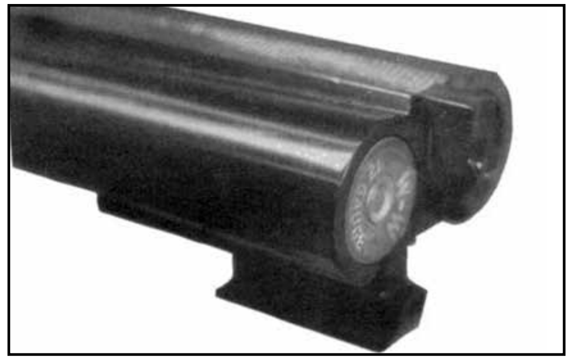

Figure 24: *The same chamber as shown in Figure 23 easily accepts an unfired 2¾ in. shell. However, when fired, this shell will protrude into the forcing cone area, causing excessive pressures, recoil, and damage to the gun.*

upland game gun in the 2 in. chamber length and prefer the 2½ in. shell and chamber length for general use. The 2¾ in. chamber and shell is considered for heavy-duty use. A considerable number of the 2½ in. chambered guns have been imported, and the length was popular in the early 1930s, when some American doubles were produced in this length (Figures 22 - 24).

Rechambering of the 2 in. and 2½ in. chambers to the current 2¾ in. chamber length should be approached with caution due to the light weight of the guns.

The 2⅝ in. chamber length is more commonly encountered than realized, since many manufacturers did not make the change when the 2¾ in. chamber length was adopted. Any barrel that is not stamped "2¾ in." should be gauged. The conversion to approximately 2 in. diameter will present no problems if the gun is in good condition, and will definitely increase the performance of the gun.

The rechambering of a current 2¾ in. chamber or the older 2⅝ in. chamber length to the 3 in. chamber length is of questionable safety regardless of the condition of the barrel or gun mechanism. Even if successful, the heavy loaded 3 in. shell with 1⅞ oz. of shot will generally render a gun mechanism useless.

10-Gauge. This has been made in two chamber lengths: 2⅞ in. and the current 3½ in. Under no circumstances should a 2⅞ in. chamber be converted to the 3½ in. chamber length.

NOTES ON CONVERSION

As stated, single- and double-barrel guns can be converted to the longer chambers with little effort other than rechambering. Some of the double-barrel guns with automatic ejectors may require retiming of the ejectors, but generally no special technique is required. The Browning five-shot semi-automatic shotgun in 16-gauge, $2\frac{9}{16}$ in. chamber length is quite common, but requires the alteration of parts internally for proper operation with the 2¾ in. length shell. Malfunctions are usually the result of not making the full conversion as recommended by Browning. Follow the directions carefully and the gun will function perfectly. It is recommended that the short, Magnum 16-gauge shells not be used in converted Brownings since the gun was not designed for this heavy load. The conversion of pumps in short chambers, such as in the Winchester Model 1912, follows the same basic procedure.

THE LONG FORCING ZONE

The example of firing a 3 in. 20-gauge shell in a 2¾ in. length chamber and the resulting effects are, in varying degrees, true with all short chambers. It is also true to a lesser degree with chambers that are the correct length but with the forcing cone of the chamber cut to accommodate the old roll-type crimped shells. These forcing cones are short and abrupt with an average length of approximately ½ in.

The old, roll-type, crimped-paper shotgun shells had a heavy piece of cardboard, commonly called the nitro wad, directly over the powder charge in the shell. Next came the felt filler wads, then the shot charge, and finally the over-shot wad with the shotgun case end rolled over to hold the wad in place.

When fired, the pressure from the powder pushed the roll crimp straight as the wad and shot column moved out of the shell. It was important that the powder gas not be allowed to pass around the wads and disrupt the shot. For this reason, the forcing cone was short and abrupt to engage the over powder nitro wad immediately as it left the shell. It was compressed by the forcing cone and held the gas pressure behind the wad.

The invention of plastic cup-shaped, over powder wad was a giant step forward. As gas pressure increased, it automatically pressed the cup edge firmly outward for a perfect gas seal. Its superiority over the paper nitro wad can best be judged by the fact that reloading manuals recommended decreasing the powder charge 10% when the plastic cup wad was used instead of the nitro paper wad.

The plastic cup powder wad completely replaced the nitro wad. Next came the plastic shot protector and then the plastic filler wads. The final step was the joining of all three components into one unit. This unit perfectly seals the gas pressure, cushions the impact of getting the shot moving, and protects the shot from being rubbed against the sides of the bore and deformed. Replacement of the old, waxed paper shell with its wads, nitro cards, and rolled crimp by the plastic shell and one-piece wad has resulted in a shotgun shell far superior in every way to the old shell.

CONVERTING OLD FORCING CONES

Fired in a barrel from which all choke has been removed, the modern plastic shell will generally produce a 5% – 10% better pattern at a given distance than a similarly loaded shell using the old wads, no shot protector, over-shot wad, etc. In a choked barrel, the new shell has the effect of increasing pattern performance approximately a half to a full degree of choke. In other words, a barrel — choke-modified and intended for the old-type shells— will produce either an improved, modified, or full-choke pattern with the new shell.

The 30 in. circle at 40 yd. has always been the method of determining the efficiency of a full-choked barrel. With a barrel chambered and choked for the old type shell, 70% is considered a good pattern. Yet, 30% of the shot is not in the circle and consequently has been lost for practical purposes. The new type shell will increase the percent to 75% – 80%, thus utilizing more of the shot that was in the shell before it was fired. This is accomplished primarily by reducing

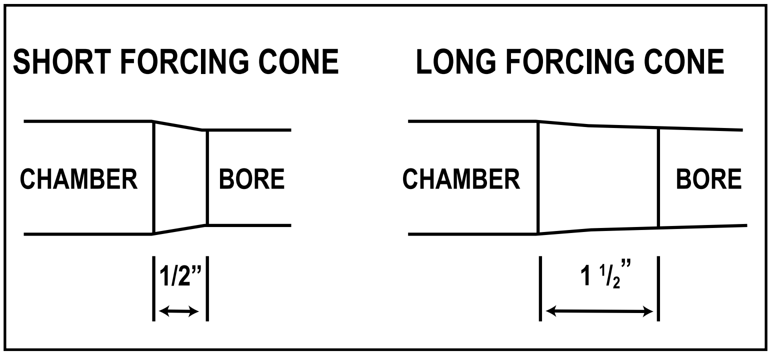

Figure 25: *The difference between a short and long forcing cone.*

pellet deformation as the pellets travel through the forcing cone and barrel.

Patterning a shotgun at the range it will be used will tell you much more about the performance your customer wants than sticking to the standard 40-yard system. The performance of an improved cylinder barrel at 40 yd. is not a guarantee of performance at the shorter ranges for which the improved cylinder is intended. The ultimate barrel will produce the desired pattern, completely without open spaces or "free holes," at the distance for which the degree of choke was intended.

The short and abrupt forcing cone always deformed some of the shot as it was pushed through the short cone, but this was a necessity with the old-type shell. It is not a necessity with the modern wad unit and folded crimp plastic shell. In fact, it actually decreases the efficiency of the new shell. With modern shells, a longer forcing cone allows the shot to pass from the chamber to the smaller bore diameter with less shot being deformed and without the gas leak problem (Figure 25).

Forcing cones from 1 in. to 3 in. in length have been tested, and the results indicate that generally a forcing cone of approximately 1½ in. in length will provide the best results with the widest variety of loads. A short forcing cone barrel rechambered to the long forcing cone will give a 5% -10% pattern increase both in density and pellet distribution. The actual pattern percent gain will vary with individual barrels, gauges, pellet sizes, and shell loads used. However, the combination of the long forcing cone and the modern shell will invariably produce a more efficient pattern.

An additional advantage of the long forcing cone is that the plastic shell body sometimes unfolds and stretches to a length longer than specified. In a 2¾ in. diameter chamber, the length can be as much as 2.90 in. instead of the correct 2.75 in. The stretching varies with the quality of the shell and the load. Cheap, short Magnum shells will stretch more than a quality skeet or trap load shell. In the short and abrupt forcing cone, this stretching allows the end of the shell to enter the forcing cone and create the bottleneck effect similar to a short chamber and with similar results.

RECHAMBERING

As with the rechambering of any firearm, safety should always be given first priority. The conversions should never be attempted without a thorough examination of the condition of the

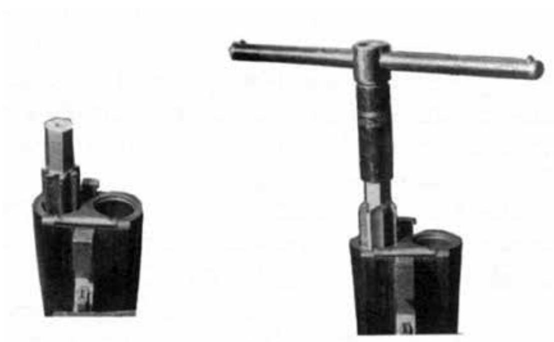

Figure 26: *Left: Barrel in vise, chamber end up, with chamber reamer in position to begin cutting new chamber. Right: T-handle wrench gives control for accurate reaming.*

gun and its components. A gun in good condition with all components locking and functioning correctly can be safely converted. Yet, a similar model in poor condition with parts and components worn and loose should not be converted. Always remember that with an older-model gun, the Magnum load of its day is probably the accepted field load of today. For this reason, you should be careful to select only field or target loads and avoid the current heavy-shot Magnum shell loads.

The flute and cutter design of the reamers is such that with proper cutting procedures, the finished chamber will be remarkably smooth and chatter mark-free. Be sure the reamer cutting edges are kept sharp by careful honing with a hard Arkansas stone. When in use, the metal chips from the removed metal should be equal in front of every cutting edge to ensure that the reamer is cutting evenly on all sides. If the chip buildup is in front of only one or two flutes, the other flutes are not cutting. Hone these flutes lightly until the metal removal is equalized.

Place the barrel in a padded vise, chamber toward the ceiling, with the chamber rear as low as possible for observation and ease of cutting. Squirt cutting oil into the chamber and onto the flutes of the reamer; the oil will help achieve a smooth cut. While the wrench used to turn the reamer should be secure to the reamer, it is necessary to exert pressure equally, allowing the tapered reamer to "feel" its own way and keep centered. Side pressure on the handle can result in a chamber wall being cut off-center (Figure 26).

After about two or three complete revolutions of the reamer, remove it straight up and out of the chamber. Wipe away all metal chips and cutting oil from the reamer. An old toothbrush and mineral spirits work fine for this job. Next, run a dry patch through the bore to remove any lingering chips and cutting oil. Check with your chamber depth gauge. Normally this procedure will have to be repeated a half dozen times or more to achieve the desired chamber depth. Regardless of the number of times, it is important that the rechambering be done slowly, the reamer and barrel cleaned each time, and the depth constantly checked with the gauge. A strong light directed into the chamber will help you see the progress of the rechambering, and you can quickly note if you are not turning the reamer with even strokes.

If initial gauging has indicated correct chamber length but the chamber has the short abrupt forcing cone and you want to rechamber for the long forcing cone, the procedure is identical with two exceptions. First, all traces of the old forcing cone must be removed. Second, to achieve this the chamber must be cut slightly longer than standard since many of the old forcing cones are pitted. The front edge of the circular-cut grooves around the gauge body is the index point for correct chamber length. However, it will generally be necessary to use the rear edge of the circular cut on the gauge as the index point for chamber depth in order to remove all of the old forcing cone. This extra length will not affect the barrel performance, since 2¾ in. shells are commonly fired in 3 in. chamber length 20- and 12-gauge shotguns.

Finish the rechambering job by polishing the chamber and new forcing cone with 500-grit aluminum oxide cloth. The Brownells choke hone tool will do the job faster and with more even results. Use this rotating tool dry for about one minute of revolution in an electric hand drill to remove any roughness, then squirt cutting oil up into the chamber and use the tool for about two minutes. The result will be a highly polished forcing cone.

The ultimate goal is to achieve as close to 100% of the pellets as possible in the shell striking within the 30 in. pattern circle with the pellets evenly distributed. The ammunition manufacturers have provided one giant step forward toward this goal with the modern shotgun shell. Using these shells in chambers of correct depth is another step forward. The long forcing cone is still another step toward that goal. There is a fourth step available: reworking the choke to achieve the maximum percentage of pellets evenly distributed in the 30 in. circle at the desired range.

Shotgun Ribs

A beautiful, well-designed, professionally installed ventilated rib is greatly appreciated by guns owners. It gives distinction and class to a gun as does few other single accessories. The words “with ventilated rib” automatically add prestige and value to a shotgun.

A solid or ventilated rib can be placed on any gun barrel, but the ventilated rib, in particular, has the easiest barrel to work on and gives the most pleasing appearance. Barrel ribs are made between ¼ in. and ½ in. in width, and the material used most is cold-drawn steel, machined to fit over the top of the barrel.

Until recently, most shotgun ribs were soft-soldered onto the shotgun barrel. To soft solder a rib, first the radius of the rib is polished bright and smooth and then the area on the gun barrel, where the rib will make contact, is polished in the same way. This is necessary when soldering ribs, since solder will not adhere to blued surfaces. Each leg of the rib is then heated with a torch so that solder will run freely, and by wetting the surface with soldering acid, together with the solder, a perfectly soldered surface is obtained. This operation is called *tinning*.

The rib is then placed in position on the barrel and each location where the brackets are to be placed is marked. These areas are then polished to remove all bluing and are finally tinned like the rib brackets.

When all spots on the barrel have been tinned and the barrel is cool, place the rib in position, securing it with C-clamps over each rib bracket. In doing so, make certain that the rib is held firmly and that it is centered on top of the barrel. Beginning at the breech, heat both the barrel and the rib carefully with a torch at the point of contact. Be extremely careful not to overheat either the barrel or rib; heat just enough so that the solder will run. To control this heat, hold a piece of soft solder in your hand and constantly use this to test the heated surfaces. When it just begins to melt on the surface of the steel, withdraw and continue to the next bracket, and so on until the rib is soldered the entire length of the barrel. When cool, remove the clamps and wash them thoroughly with hot water. This will remove the acid that would otherwise rust the bright surface of the steel. Wipe dry and if the work is to stand for any length of time before bluing, oil it lightly with gun oil. A shotgun barrel with ventilated rib is shown in Figure 27.

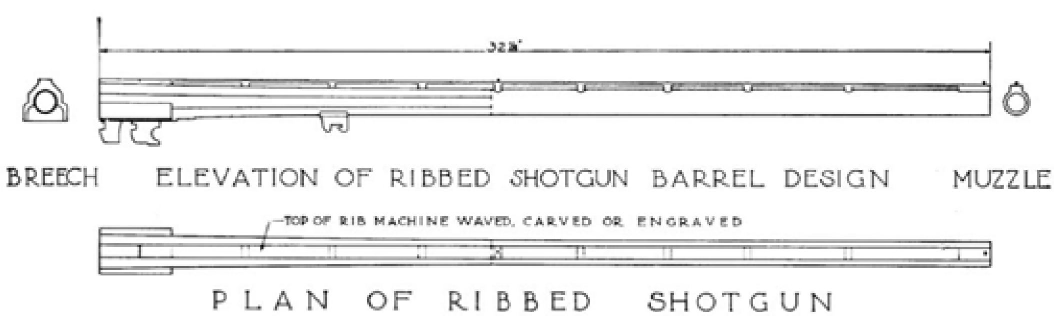

Figure 27: *Elevation view of a shotgun barrel with ventilated rib.*

RESOLDERING RIBS

Double-barrel shotguns frequently have the rib loosened from the barrels at the forend lug. To reunite the rib, carefully raise the loose rib as far as possible without bending it, and hold it in this position by inserting a small wooden wedge. Then, with a thin scraper, scrape both barrels and rib where they come into contact with each other. Wrap the barrels well in different locations with soft iron wire; four to six strands to each wrapping, with the ends twisted together, are sufficient. Place the wedges between the wire and rib. Any small, round, cold-drawn steel may be used, as long as the pressure can be placed between the wire and ribs. With the ribs in place, use a torch to heat the raised section of loose rib and barrels; tin these parts as discussed previously with rosin and small soldering wire. When both rib and barrel are tinned, put the rib in place by wrapping wire over this section, and hold it in place with a wedge. It may require two or three wrappings of wire in the location to hold a rib in place before a perfect job of sweating is achieved. Complete the sweating operation with the torch.

Chapter 7 - Restoring Rifle and Shotgun Barrels

Introduction

Any experienced gunsmith knows that the bore dimensions and smoothness of the rifling in a rifle barrel are extremely important for accuracy in shooting. Most barrel blanks are now rifled using the broaching method, in which a long tool with serrated edges, or broach, is pushed through the barrel to form the required shape. Although this method produces very smooth barrels, lapping always improves them. Lapping is also an excellent way to restore older, worn barrels to an acceptable condition.

A rough, pitted bore tends to pick up leading or metal fouling as projectiles are fired through it. Shotgun barrels can develop corrosion and pits, which cause erratic shot patterns and make it difficult to clean the bore. Cleaning a rough bore is tedious work, but a barrel with a smooth, well-polished bore is more accurate, so your hard work will be worthwhile.

Shotgun barrels can develop corrosion and pits, which cause erratic shot patterns and make it difficult to clean the bore to avoid further pitting.

There are several ways to restore a rifle's accuracy if there are problems with the barrel. The most obvious way is to install a new barrel, especially if the rifle is still being manufactured. If a replacement barrel is not available from the manufacturer, a barrel will have to be custom-made by a qualified gunsmith, which can be an expensive undertaking. Gunsmiths are frequently called upon to restore barrels on antique firearms because a new barrel would lower the collector value.

Before discussing the restoration of rifle and shotgun barrels, let us take a look at laps and lapping, and their purpose in the firearm industry.

Laps and Lapping

In general, lapping is a rubbing process for removing minute amounts of metal from surfaces that must be precision-finished in order to:

- Produce true surfaces
- Improve dimensional accuracy
- Correct minor surface imperfections
- Provide a close fit between two surfaces

Filing, milling, or grinding metal produces relatively rough work at best. However, you can remove imperfections by lapping, which requires a good lapping tool (lap), a compound suitable for the job, and some patience. The compound should be approximately the same hardness as the material to be lapped, while the lap itself should be considerably softer than the material. A single lapping compound will not serve all purposes. Therefore, manufacturers of lapping compounds provide guides for selecting the proper compound for a particular lapping job.

LAPPING COMPOUNDS

Both external and internal universal laps are available, but most gunsmiths make their own. To use an external lap, apply the appropriate

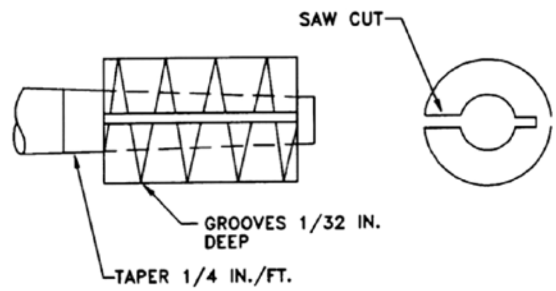

Figure 1: *A cast iron lap used for lapping the inside of a hardened steel receiver.*

lapping compound generously to the object you want to lap and also to the lap, and process either by hand-polishing or by rotating the object in a lathe while applying the lap by hand. The revolving speed should be approximately 300 rpm, and the lap should move across the work slowly and with light pressure. Check the size and finish of the work frequently, and use a hot, strong cleaning solution to clean all surfaces before finally drying them with a clean, soft rag.

The lap may be very simple, consisting of a strip of some type of abrasive cloth attached to a shaft, or it may be elaborately constructed of lead, copper, cast iron, etc. Figure 1 shows a cast iron lap used for lapping the inside of a hardened steel receiver. The workpiece is secured in the lathe chuck, while the lap, on a tapered mandrel, is secured in a drill chuck in the tail stock of the lathe. While the work rotates, the lap is slowly fed into the receiver. Conventional automotive valve lapping compound will suffice for most applications, but Clover® abrasive compound kits seem to suit most needs of the average gunsmithing shop. Two kits, No. 4 and No. 6, seem to be the most popular.

Clover Kit No .6. Six different grit sizes are available in this kit. The grit consists of silicon carbide formulated with a special grease base that lasts a long time and does not break down under heavy use. The sizes (120- to 800-grit) are ideal for nearly all fitting, lapping, and running-in operations. They are also good for the initial work or reworking of metal-to-metal fits where both metals are steels.

The abrasives in kit No. 6 are not designed for use between steel and aluminum alloys, because silicon carbide crystals will embed in the softer metal. The kit contains 2-oz. metal cans in the following grits:

- E, 120 (coarse)
- D, 180 (medium coarse)
- B, 240 (medium fine)
- 1A, 320 (very fine)
- 4A, 600 (extremely fine)
- 5A, 800 (micro-fine)

Clover Kit No. 4. This kit contains four different grit sizes of ultra-fine, water-soluble aluminum oxides, and is formulated with a petroleum-based, emulsion-type carrier, which is water soluble and easily removed from the work surface once you are finished. It is particularly useful for lapping inside surfaces where solvents are difficult to apply. The crystal used is aluminum oxide, which is rounded and breaks down into smaller rounded pebbles as it is used. These crystals are extremely tough and have great durability and wear resistance, but they do not embed because they are not sharp. While these compounds cut slower than others, they are recommended for metal-to-metal fitting situations where steel is fitted to aluminum alloy, because the crystal will not embed in the softer metal. The grit sizes in this kit are as follows:

- 4A, 600 (14 microns)
- 5A, 800 (9 microns)
- 6A, 1000 (5 microns)
- 7A, 1200 (3 microns)

Three types of lapping medium normally used for lapping in the firearm industry are:

- Metal laps and loose abrasive mixed with a lubricant
- Bonded abrasives for commercial production work
- Abrasive paper or cloth

One common lap consists of a split sleeve and a tapering holder or arbor, which is used to expand the sleeve to fit the hole being lapped. Lapping compound is applied to the lap and then moved gradually through the hole until the desired finish is obtained. The split in the lap allows it to be expanded as it becomes worn.

The busing forming the lap frequently is made of cast iron or copper. The actual lapping operation involves moving the lap in and out to cover the entire surface of the hole in the case of internal lapping. The lap length should be about three times greater than the diameter of the hole being lapped.

Be careful when applying the abrasive compound, especially toward the final stages of the operation. If you apply too much, the ends of the hole will enlarge because of the abrasive particles crowding under the edges of the lap.

LAPPING OPERATIONS

When lapping is done precisely, metal can be brought to a given dimension with greater accuracy and a finer finish than by any other means.

Lapping operations fall into two categories: hand lapping and machine lapping. Hand lapping is frequently done in most gun shops, while machine lapping is usually done in industrial applications where speed is of the utmost importance. Hand lapping, although slow and tedious, avoids the high cost of lapping machines, and every gunsmith should know the basic principles of hand lapping for truing external, internal, and flat surfaces. Obviously, hand lapping is employed for lapping small quantities of work.

PRACTICAL APPLICATIONS

Shotgun Barrels. For best results, shotgun barrels should be lapped with power tools—either a drill press or a speed lathe. Laps can be made from steel, lead, or wood. However, the rod should be constructed of steel, since wood will vibrate too much when turned at high speed.

Since lapping is really polishing, one of the easiest and least expensive ways to lap is to use a shotgun polishing head like the one shown in Figure 2.

In general, it consists of a steel head designed to rotate. With the shotgun polishing head, polishing the choke to a mirror-like finish without changing its dimensions is as easy as polishing the straight part of the bore.

When using a electric hand drill, clamp the barrels in a bench vise. Then chuck the rod in the drill motor before inserting the polishing head in the breech end of the barrel. Start the motor and push the revolving rod slowly forward and back.

You can use coarse strips of abrasive cloth to remove lead and scratch marks; use the finer grit sizes for polishing.

LAPPING RIFLE BARRELS

Since rifle barrels have a rifled interior, general polishing will not work because the rifling will be removed in the process. The lap must spin with the rifling in the bore as it is being pushed up and down the interior of the barrel. The first step, therefore, is to remove the barrel from the receiver and take accurate interior measurements of the lands and grooves. You can use calipers to measure at each end of the barrel, but for best results, use a soft lead slug slightly larger than the bore itself. This lead slug can be started into the muzzle end of the barrel and pushed or gently tapped through the entire length of the barrel to fall out the breech end. The lead slug will give a perfect imprint of the rifling (lands and grooves) on the inside of the barrel, and you can measure these imprints with a micrometer to get the dimensions you need.

Continue by making a lapping rod out of steel with a diameter large enough to slide easily through the bore. The head of this rod should be turned or filed as shown in Figure 3. The

Figure 2: *A lapping tool.*

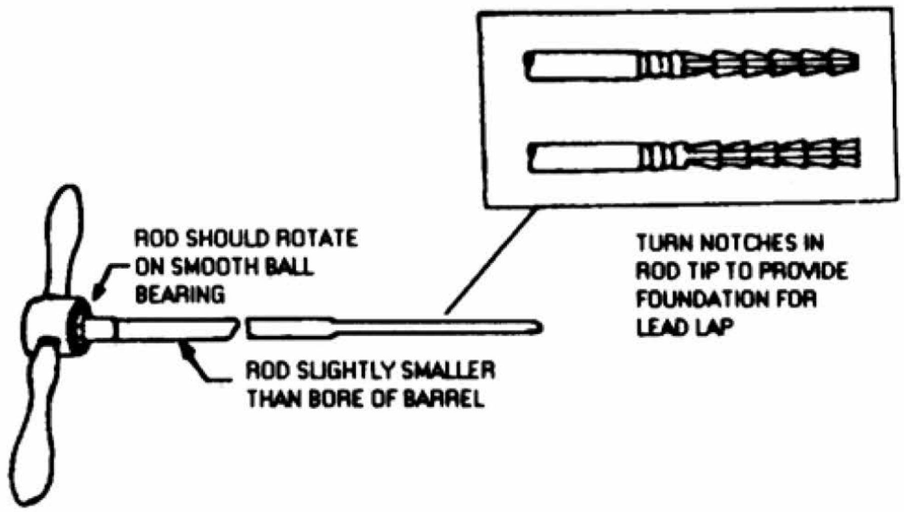

Figure 3: *Details of barrel-lapping rod.*

opposite end of the head should then be brazed, silver soldered, or welded to a handle assembly so the rod will turn freely on a smooth-working ball bearing.

Once the rod has been made, secure the barrel in a vertical position in a bench vise. Wrap a piece of cotton twine around the lapping rod just below the rod tip, enough to provide a snug fit inside the barrel. Now insert the rod from the breech end of the barrel, pushing it in and stopping it about ½ in. from the muzzle of the barrel. Heat the barrel with a propane or other low-heat torch until the barrel is just hot enough to melt solder, yet not hot enough to affect the metal finish. When the barrel reaches this temperature, use a ladle to pour melted lead carefully into the bore to form a solid slug around the tip of the rod, as shown in Figure 4. Let this slug cool slightly, then push it about an inch out of the muzzle of the barrel. Be careful not to push it out all the way or you will have to start over. Note that the slug now has the full imprint of the barrel's rifling and is molded to the exact dimensions of the bore. With the lap partially protruding from the muzzle, file off any burrs or fins that may prevent the lap from being pushed and drawn through the barrel.

Now, change the position of the barrel. Place it horizontally in the vise, with the handle of the rod projecting from the breech end. With the lap still projecting from the muzzle end only about three-fourths of its length, completely coat the lap with a suitable lapping compound—fine valve lapping compound or Clover lapping compound, for example. Squirt some oil into the bore from the breech end as shown in Figure 5. Grasp the rod handle in both hands and draw the lapping rod backward, slowly and evenly through the barrel, until about half the lap projects into the chamber or, if there is no chamber, out the breech end of the barrel. Again, be careful not to let the lap pull out all the way; if it does, you will have to start over. Now push the rod so the lap travels back toward the muzzle. Continue this backward and forward motion. Recoat the lap with compound as often as necessary to maintain a smooth cutting action.

The amount of time required to obtain a good job depends on the condition of the bore when you started. Some jobs will be complete after 20-30 strokes, while others may take hours to complete. During the lapping operation, if the lap becomes worn or loose, you will have to melt it down and cast another lap.

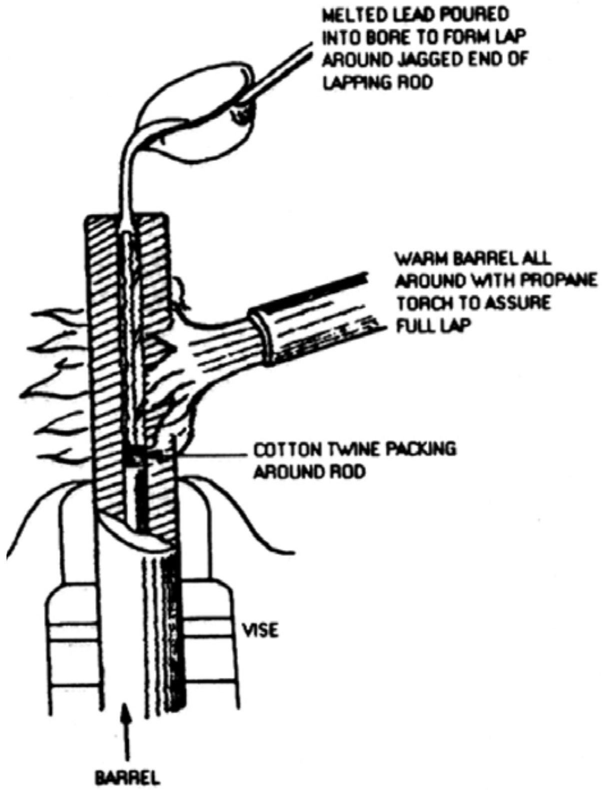

Figure 4: *Method of pouring a lead lap into a rifle barrel prior to the lapping operation.*

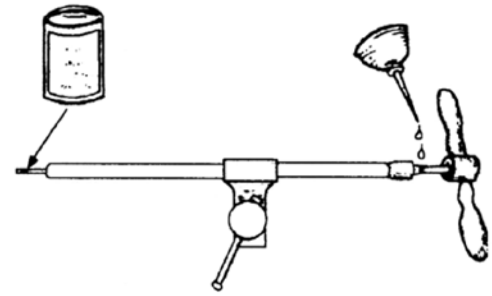

Figure 5: *The barrel must be secured horizontally during the lapping operation.*

Often, lapping a rifle barrel will remove every pit and tool mark in a short period of time, resulting in a fine, smooth, accurate barrel. However, even if lapping does not remove every mark, you will always see some improvement.

When you are finished, withdraw the lapping rod completely. Clean the bore of the barrel with a solvent, using a tight-fitting cleaning patch on a rifle cleaning rod. You will get better results if you soak the entire barrel in a solution of Brownells D'Solve, then blow it dry with compressed air. Immediately oil the bore, along with the rest of the barrel. Remember, a proper lapping job will almost always improve the accuracy of any rifle barrel—even a brand-new one.

There are several methods of obtaining a free-turning rod. Figure 6 shows one method. This drawing gives complete details for the construction of one type of barrel lapping tool.

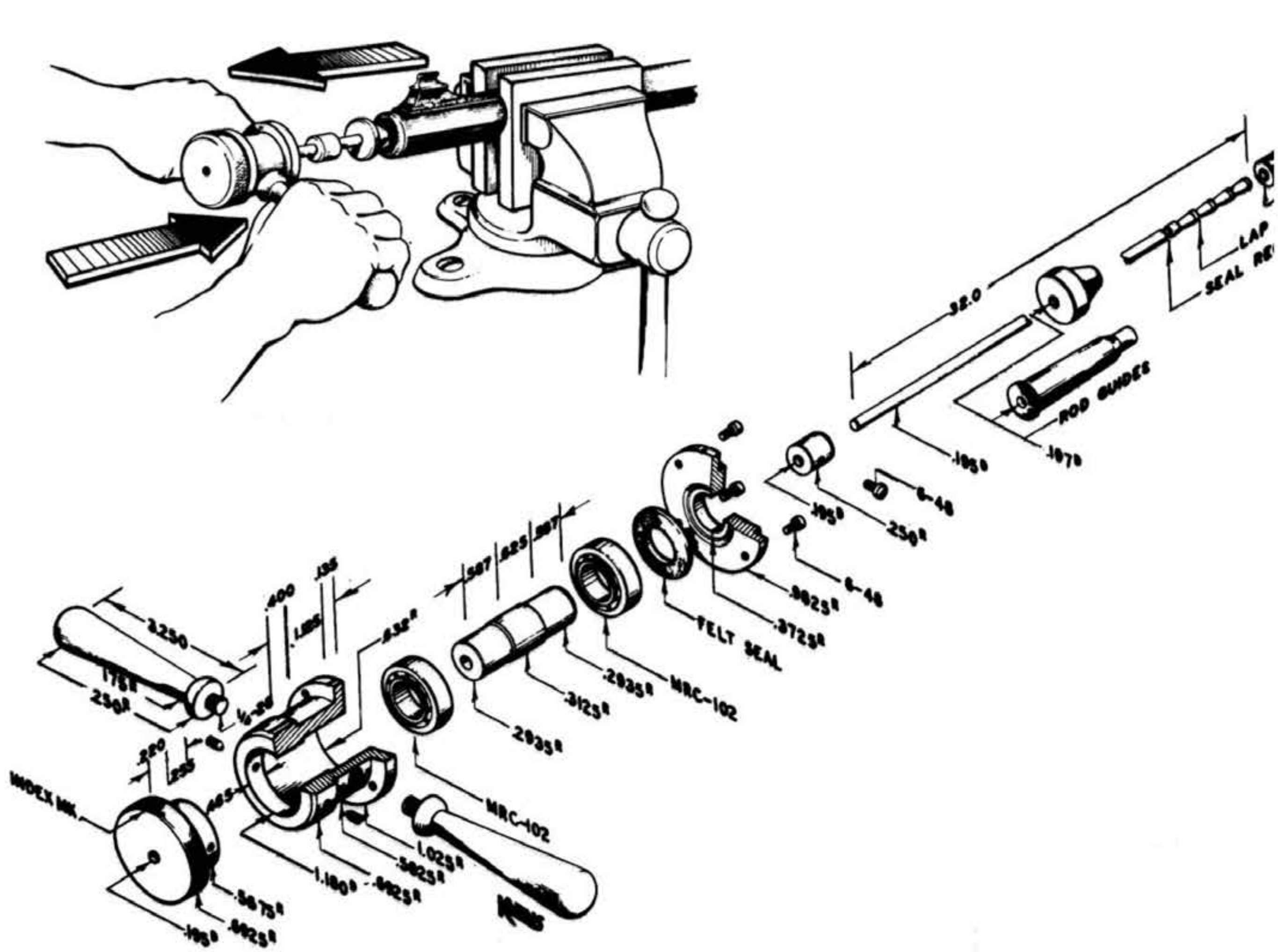

Figure 6: *Exploded view of a barrel-lapping tool.*

Shotgun Barrel Alterations

There are many shotgun barrel alterations that can help restore the gun and also improve its performance. For example, shotgun bore reamers, like the one shown in Figure 7 , are used for back-boring (enlarging the bore) and choke modification in shotguns. They are also ideal for rejuvenating a badly pitted shotgun barrel. After one pass with the proper bore reamer the shotgun bore will look new.

The lead angle on a Clymer shotgun bore reamer matches the angle of most chokes and will therefore blend into an existing choke when back-boring. The 8 in. left-hand spiral flutes provide smooth cutting, which results in a good surface finish.

Clymer bore reamers are stocked in the cutting diameters listed below. Variations are available on special order.

Gauge	Diameters
10-gauge	.765, .770, .775, .780, .785
12-gauge	.720, .725, .730, .735, .740
16-gauge	.652, .657, .662, .667, .672
20-gauge	.605, .610, .615, .620, .625
28-gauge	.540, .545, .550, .555, .560
.410-gauge	.400, .405, .410, .415, .420

If the bore of a shotgun is too badly pitted to be corrected by polishing, back-boring is the only solution other than installing a new barrel. However, before purchasing a shotgun bore reamer, you must determine the inside diameter of the shotgun bore in question.

Let us say you have an old Browning 12-gauge semi-automatic shotgun. The barrel is terribly pitted and you have to put it back in good condition. First, carefully measure the inside bore diameter of the barrel using a micrometer and Brownells inside calipers. Assume that this measurement is 0.725 in. Looking at the above list, we find that 0.730 in. is the next largest size of standard shotgun bore reamer available. This size is probably the best choice. If the bore diameter measures 0.730 in., then you would go to the 0.735 in. reamer, and so on.

When you order the reamer, you will also need a 34 in. extension handle to fit the reamer properly. If the back-boring is to be done by hand, you will need a T-handle extension. Since shotgun bore reamers must be driven as accurately as possible, Clymer offers three sizes of 34 in. extensions. Large fits the shanks of 10-, 12-, and 16-gauge bore reamers; medium fits 20- and 28-gauge tools; and small fits a 0.410 bore only.

Any way you look at it, back-boring a shotgun barrel is not something that can be done quickly. Even if you use power tools, the job is going to take a long time. You cannot expect to slap some

Figure 7: *Shotgun bore reamers for back-boring and choke modification.*

cutting oil on the reamer and run it through the bore as you would when drilling a ¼ in. hole through a thin piece of steel. You must go slowly, and frequently remove the reamer for cleaning and re-oiling. It will probably take about two hours to back-bore a shotgun barrel if you use power tools; it will take a little longer if you do it by hand.

Bore reamers are relatively self-guiding, but you must go slowly. At the slightest sign of any stress or resistance in the cutting action, you must remove the reamer, thoroughly clean off any cuttings, completely wipe out the bore, re-oil the reamer, and cut a little more. Continue this operation until the end of the reamer barely sticks out of the muzzle of the barrel by just a few thousandths of an inch.

Once again, clean the reamer and also the bore of the shotgun, making sure you remove all oil and cuttings. Even a tiny piece of metal left in the bore can cause damage to the bore.

Once the reaming operation is complete, there will probably be some tool marks remaining. Consequently, the shotgun bore should be lapped or polished as described earlier in this lesson.

The degree of polish on the inside of a shotgun barrel is very important. Lead shot tends to stick to steel or lead, and if it goes through a rough bore, it develops flats, causing poor shot patterns. The smoother the shotgun bore, the better the shot patterns. A smooth barrel with the correct load will outperform a rough barrel consistently.

CHOKE-REMOVING REAMERS

For the back-boring operation, you can obtain reamers to open up the present choke or leave the same degree of choke in the barrel. However, in some cases, you may want to open the choke on a shotgun barrel that does not require back-boring. Again, a reamer is used. The choke-removing reamers, like the one shown in Figure 10, are used to remove a choke or to open the parallel section of a choke to give less constriction (for example, when changing a "full" choke to a "modified" choke). These reamers have eight high-spiral flutes that give excellent cutting action. In use, the tool is inserted from the breech (chamber) end and pulled out of the muzzle while either the barrel or tool is rotated. A gentle lead angle combined with a 2¼ in. long straight section ensures that the reamers will run true to the existing bore axis. A ½ in. long circular ground section at the heel of the tool prevents spiral rings from being left in the bore. The cutting diameters listed in Figure 8 are available from stock, while other diameters can be special ordered. Back-boring can make neglected bores look new, as shown in Figure 9.

Figure 8: *Choke-removing reamers are used to remove a choke or to open a parallel section of a choke to give less constriction.*

***Figure 9**: Many fine shotguns, like this Winchester Model 21 double-barrel, have neglected bores that can be made to look like new by back-boring.*

CARE AND USE OF REAMERS

Proper care and handling of reamers is extremely important. When not in use, always store reamers in their shipping containers or plastic tubes to prevent nicks in the cutting edges, which can cause rings in the surface of the barrel or chamber.

Most experts agree that a reamer should be honed only to remove a nick or burr. A reamer that has been properly ground and cared for should turn out quite a few jobs before it becomes dull. When it does become dull, you can return the reamer to the manufacturer for resharpening. This service is usually offered to customers at a reasonable cost.

Before using any reamer, you should double-check the dimensions to be sure it is the tool you intend to use. When using reamers—either in the lathe or by hand—use the best grade of sulfur-based cutting oil available. The more sulfur in the oil, the better; this facilitates cutting and gives a better finish. Thread-cutting oil, such as that offered by Ridgid® Tools, is excellent for use in reamers.

When cutting with reamers, be especially careful. To prevent the flutes from loading with metal chips, which can cause the tool to cut oversize, the reamer should be cleared every 1/32 in. of depth. Brush the reamer with a small brush to remove any chips.

A floating reamer holder used in the tailstock of the lathe allows the reamer to seek a true center of the bore and helps avoid cutting the base diameter too large. Run the lathe at its lowest rpm and feed the reamer in slowly so it will not grab and chatter as it starts to cut. If it does chatter, remove the reamer and take a drill slightly larger than the neck of the reamer and drill out the chatter marks. Replace the reamer and resume cutting.

When hand-chambering, be sure to hold the reamer true to the bore. Use caution, since the reamer may snap off if it is cocked to the side. Press down firmly on the reamer when beginning the cut and then turn it slowly so the tool will not jump and chatter.

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Soldering, Brazing, and Welding

Now that you are learning about restoring firearms, you should obtain a good knowledge of soldering, brazing, and welding. All three of these techniques will prove invaluable in your career as a professional gunsmith.

With this knowledge and the proper equipment, the gunsmith can repair many broken gun parts so that they will last as long or longer than the original part.

Soldering is useful for mounting sight ramps and for resoldering old double-barrel shotguns when the soldering deteriorates to the point where the parts might come apart upon firing. This latter technique is not for the amateur: the job takes a set of special barrel wedges, clamps, and the professional skill that few gunsmiths possess. But if you put forth much effort, you can do it (Figure 10).

It is best not to apply heat to any part of a gun until you are absolutely certain that you know what to do. However, a beginner can make repairs on certain noncritical parts by silver soldering, if care is exercised. For example, the thin, semi-fancy trigger guards of certain double-barrel shotguns are subject to breakage; these may easily be repaired by silver soldering, and then reblued. Tangs on some of the older Winchester Model 92 lever-action rifles are often found broken, and can be helped by silver soldering. Many other noncritical parts found on firearms—hammer spurs, triggers, and swivels—can also be helped by silver soldering.

Figure 10: *Some rifle front sight ramps are designed to be soldered onto the barrel. Your knowledge of soft soldering and the proper tools will do the trick.*

Regardless of the type of metal joining—soldering, brazing, or welding—there are certain requirements common to all three:

- Cleanliness
- Flux
- Proper amount of heat

The first requirement—cleanliness—means that the metal to be joined must be clean, bright, and absolutely free of scale, grease, oil, and dirt. This could mean, in some cases, that the bluing should be removed, such as at the muzzle of a rifle barrel prior to sweating on a sight ramp. The main purpose of flux, the second requirement, is to prevent oxidation. When metal is heated, it will oxidize, preventing the formation of a good joint. Flux, when properly applied, will help prevent this. The third requirement—heat—must be sufficiently high to flow the joining metal, and also to raise the temperature of the parts to be joined. If you can meet these three requirements, you are well on your way to becoming an expert at soldering, brazing, and welding.

Soft Soldering. Sight ramps, shotgun barrels, rimfire barrel liners, scope sight bases, and some other firearm accessories can be attached by soft soldering. However, most solder found in your local hardware store is designed for electrical and plumbing applications, and is not the best for use on firearms. Hot caustic bluing solutions attack the soft-soldered joints, and in some cases will render the joints useless, requiring that they be resoldered.

Brownells solved this problem with their Hi-Force 44™ solder, which contains 4% silver and 96% tin, and can be used on all types of gun metals except aluminum. Best of all, users have reported that parts joined with this product showed no effects when immersed in the hot caustic bluing solution.

After you clean the areas on both pieces to be joined, coat them with solder. This process is called tinning. Heat the areas with a torch — propane will do — and apply soldering flux, such as No. 4 Comet. Reheat the areas to a temperature high enough to melt the solder and spread a thin coat of melted solder completely over the areas to be jointed. This is accomplished by heating the metal — not the solder — with the torch. By doing so, the metal will melt the solder when it reaches the proper temperature. If the solder is heated and melted onto the surfaces, it will not make a good bond or, possibly, none at all. While the surfaces are still hot, take a thick rag and, with a quick swipe, wipe off all excess solder. You will not get a good joint if there is too much solder between the two pieces to be joined. Then let the parts cool at room temperature until they can be easily handled.

Once cool, the parts can be placed exactly in position and then clamped securely. Heat the parts again with a propane torch to a point where the solder flows freely. You can feed additional solder to the two joining areas, either around the edges of the objects or possibly through screw holes in the pieces. Be careful not to clog the holes if this latter route is taken. Immediately wipe off any excess solder with a dry cloth.

If you are soldering a part on a blued surface, remove the bluing only where the parts will join, so that all surfaces that can be seen will retain the blue. Be careful not to apply too much heat or you will discolor the surrounding blued surfaces. Parts that have been properly cleaned and tinned with the Hi-Force 44 solder and then joined together will be permanently attached and will withstand any rough treatment. It is not recommended for repairing broken parts that will be exposed to strain — even the slightest bit (Figure 11).

Figure 11: *Gun parts under any type of stress should not be soft soldered. Silver solder is surprisingly strong and will take care of 90% of non-critical gun parts.*

Silver Soldering. This technique will find the most uses around the gun shop. Silver solder becomes fluid enough with heat to flow through small cracks, and although it requires more heat than soft solder, it normally requires less heat than conventional brazing. For gun work, a solder that flows between 1,000°F and 1,200°F is best; anything higher will render some metals useless for gun work. Clean the parts to be joined as described previously, then hold them in position. Apply flux to the joining surfaces. Then, heat both parts from a dull to bright red — depending upon the metal to be joined — and when hot enough, touch the silver solder to the joint, which will "suck in" the solder between the pieces being bonded.

Since you will encounter many types of metals and alloys during the course of your work, selecting the proper solder for a particular job can be difficult. Knowing the exact proportions of solder and flux — and the right solder and flux — requires considerable experience. Fusion solders come already ground in their own special flux in the correct proportions. Because of this, practically anyone with a minimum amount of experience can do top-quality soldering using the following types of solders.

S-4 1000 Silver Braze. This is a low-temperature, high-strength brazing alloy for use when tight-fitting joints with a minimum amount of fill are desired. It melts at 1,000°F. When using this solder, make sure that you mix it well and keep the container tightly closed.

S-4 Silver Braze. This solder closely resembles S-4 1000, but has a wider melting range and higher flow point for better filling characteristics. This is the solder to use when putting on front ramps that do not match the barrel exactly. It can also be used for joining small parts where chips of steel have been broken, or when it is impossible to hold parts together for brazing.

DMS-1200-750 Non-Flowing Silver Braze. This solder does not flow when it melts. It can prevent runny solder, and helps you keep from losing the alignment in jig setups, which can happen when solder begins to run. It is excellent when used for ramps, ribs, sights, and repairs where the fit does not have to be perfect.

For most silver soldering work, Brownells Silvaloy 355 is good. It melts at about 1,100°F and flows at around 1,150°F. It has the lowest melting point of any commercial silver solder, and is excellent for use on gun parts. It comes in both wire and ribbon forms, for use in most gunsmithing applications.

An oxyacetylene welding outfit is one of the most useful pieces of equipment for the gun shop. The acetylene torch alone may be used for bending, forging, hardening, tempering, and soft soldering. With the oxygen added, it can be used for silver soldering, brazing, and welding. Almost any good set will suffice for gun work, but one favorite has been the smaller unit (with tanks) that can be easily rolled or carried to various locations. It is manufactured by Uniweld®. It is known as an aircraft welder, and comes in kit form with regulators, hoses, tips, and tanks. The tanks are placed in a rolling carriage and can easily be rolled from one area in the shop to another.

Figure 12: *Oxyacetylene tools.*

Tip sizes are important and should be selected depending on the type of work that you will be doing. For example, size 0 is small and good for spot annealing on some case-hardened receivers prior to drilling and tapping for scope mounts. Size 4 is good for bending bolt handles to accept telescopic sights, while those sizes in between are used for various welding and brazing applications.

You must follow certain safety precautions when using welding equipment. Eye protection, such as a pair of welding goggles, is absolutely necessary. Also important is your method of lighting the torches. Never use a cigarette lighter. Use a flint-type torch lighter designed especially for lighting acetylene welders. You also should have some type of body protection, such as welder's gloves and a leather welder's jacket. The latter is rather expensive, so many gunsmiths wear cotton coveralls or a denim jacket instead. Be extremely cautious about the surrounding atmosphere. Obviously, you would not want to use the torch around any combustible materials or fumes; that could be disastrous. Many auto mechanics have lost their lives when repairing gas tanks. They drain all the liquid gas out, but forget about the fumes—when the torch is applied, an explosion results.

For welding and brazing, the gunsmith will need an assortment of welding and brazing rods. One type of rod that will fulfill most of your needs is the 3½ in. nickel steel welding rod.

When welding, securely clamp your work before applying the torch. Many gunsmiths have an assortment of jigs suitable for practically any job. For welding small parts, many gunsmiths use two conventional vises for holding the work, one half of the part in each vise. The vises are then swiveled until the joint is in perfect alignment. If the parts are very small, use alligator clips with Brownells Heat Stop™ to prevent the springs from losing their temper too quickly. Have plenty of these clips on hand because eventually the springs will be of little use and will have to be discarded due to the high heat used in welding.

Each welding torch tip normally comes with recommendations for the proper gas pressure (set the regulators accordingly). Follow these recommendations until you have reason to do otherwise. The chart in Figure 13 should be helpful.

To use the torch, first turn on the acetylene and ignite it with the flint-type striker. This will give a dirty, sooty flame. Then turn on a small amount of oxygen and the flame will clear. If the oxygen is below normal requirements, the light-colored inner portion of the flame will be long, or "fishtailed." This is known as a reducing flame, one which has an excess amount of acetylene. As the amount of oxygen is increased, the light-colored inner portion, or oxygen cone, will shorten and become clearly defined. This is known as a neutral flame, one which contains enough oxygen to burn all the acetylene; this is the type of flame you will use most around

Tip Size	Drill Size	Min. Oxygen Pressure (psi)	Max. Oxygen Pressure (psi)	Min. Acetylene Pressure (psi)	Max. Acetylene Pressure (psi)	Min Acetylene Consumption (cfh)	Max. Acetylene Consumption (cfh)	Metal Thickness
000	75	½	2	½	2	½	3	up to 1/32"
00	70	1	2	1	2	1	4	1/64" - 3/64"
0	65	1	3	1	3	2	6	1/32" - 5/64"
1	60	1	4	1	4	4	8	3/64" - 3/32"
2	56	2	5	2	5	7	13	1/16" - 1/8"
3	53	3	7	3	7	8	36	1/8" - 3/16"
4	49	4	10	4	10	10	41	3/16" - 1/4"
5	43	5	12	5	15	15	59	1/4" - 1/2"

Figure 13: *Recommended acetylene welding settings.*

the shop. If the oxygen is increased even more, the oxygen cone will grow very short, and there will be an excess of oxygen known as an oxidizing flame.

Too much of either gas does steel no good. For example, the reducing flame will carburize the metal and harden it. However, it is recommended for brass, since it will not burn it. The oxidizing flame will burn the carbon out of the steel and ruin it. Remember, when welding or bending bolt handles, never let the oxygen cone in the center of the flame touch the metal or it will quickly burn out the carbon in the steel.

When welding, the general principle is to heat the two parts enough that they begin to flow and fuse together. Then use the welding rod to fill in the gaps. This is easier said than done, and you should practice a lot on scrap metal before working on good parts.

In addition to repairing small parts, the welder is frequently used in gun shops to weld on new bolt handles. You can purchase these handles from various sources for only a few dollars a piece. The bolt ends are normally cut at an angle; when cutting off the original bolt—prior to welding on the new one — this bolt should be cut at an angle, too.

Bolt welding jigs are available, but many gunsmiths prefer to use two vises — one fixed and one portable—to hold the bolt and bolt handle. The steel vises draw sufficient heat from the lugs, provided they are placed correctly. Then, by "playing" the flame of the torch away from the bolt body, the job can be done in a relatively short period of time. The usual procedure is to "tack" the two pieces first, then let them cool slowly at room temperature. However, before doing this, some gunsmiths pack the inside of the bolt body with wet asbestos to help keep the temperature down. The entire bolt body and accessories must be completely stripped before any heat is applied. This includes the firing pin (striker), striker spring, extractor, and ejector.

When the part has completely cooled, heat the two parts again and fill in the voids with the 3½ in. nickel steel welding rod. If you have never done this, or if your welding experience is limited, it is strongly recommended that you do your first couple of jobs under the supervision of a professional. The locking lugs on any bolt are hardened and heat-treated to withstand a given amount of pressure. Any heat that will color the steel will do damage to these lugs, so use extreme caution when applying heat to the bolt handle.

BASIC WELDING PRINCIPLES

The basic principle of welding is realized in a common operation performed by the old-time blacksmith or gunsmith over the anvil, where two pieces of wrought iron or steel were heated to a white heat and then hammered together. The best blacksmiths and gunsmiths could perform the work so skillfully that a joint could not be detected. If this kind of joint is tested in a testing machine to pull it apart, it would probably fail at the weld rather than in the actual metal, but a good hammer weld should have about 75% of the strength of the metal itself.

Chain was once made by hammer welding, and the familiar joints for this type of work were also used in making Damascus shotgun barrels, as shown in Figure 14.

Operations of this kind are rather primitive by today's standards, but the basic principles of welding may aid the gunsmith when using more modern methods.

Wrought iron is a better welding material than steel, because when steel is heated, the parts become coated with oxide or iron in the form of a black scale. If this is not removed, the weld will be defective. In the case of wrought iron, the metal may be safely heated to a temperature which will melt the oxide, that is then forced out during the hammering. But since this is too high a temperature at which to work steel, it is necessary to use a flux— usually borax. Borax powder and fine, clean sand in equal parts makes a good flux, especially if mixed with 25% iron (not steel) filings. However, in most cases, it is probably better to use one of the welding compounds that are sold specifically for different kinds of welding.

Extensive use was made of what is basically hammer welding in the fabrication of Damascus gun barrels, which were popular around the latter part of the nineteenth century. In general, Damascus barrels consist of a combination of forged iron and steel. Strips of iron and steel are braided and formed into a band. This is then wound around a mandrel and welded. The manufacturer proceeds little by little; the form is worked with light hammering until all the small rods or wires are joined into a solid piece. The mandrel used as a form is then removed by boring it out. Depending upon how the wires are braided and twisted, a pattern will appear on the finished barrel after browning or bluing takes place.

The cheapest Damascus barrels were the so-called "brand" Damascus barrels. Better-quality types were the Horseshoe Damascus, Rose Damascus, Bernard Damascus, Crolle Damascus, Moire Damascus, and Laminette Damascus. Other fine types of Damascus included those made in England, known as "Laminated Steel," and the genuine English Damascus produced in Marshall's workshop in Birmingham, England. Confidence in the quality of Damascus barrels was so great that even ordinary steel barrels were either painted or covered with decals showing Damascus patterns. You can still occasionally find these imitation Damascus barrels.

Figure 14: *Damascus shotgun barrels have beautiful patterns, but all of them can be deadly to shoot, especially with modern loads.*

The improvements in barrel steels drove Damascus barrels off the market generations ago. But until about the year 1900, approximately one-third to one-half of all Belgian shotguns were produced with Damascus barrels.

ELECTRIC WELDING

You cannot learn electric welding by reading alone; skill comes only with practice. However, the following section gives the basic principles.

Four simple factors are of prime importance in welding:

- The correct welding position
- The correct striking of the arc
- The correct arc length
- The correct welding speed

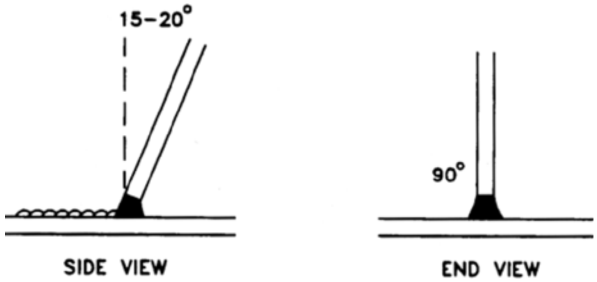


Figure 15: *Relationship of welding electrode to work.*

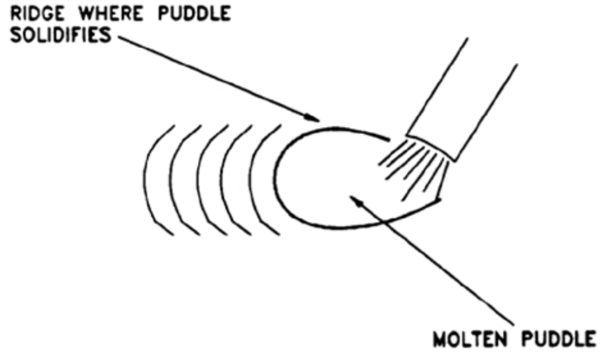


Figure 16: The ridge where the molten puddle solidifies should be approximately ⅜ in. behind the welding electrode.

For arc welding, hold the electrode holder in your right hand (for right-handed persons), and then touch your left hand to the underside of your right hand for support. Place your left elbow by your left side. Whenever possible, weld using both hands. This gives you complete control over the electrode's movements. Also, whenever possible, a right-handed person should weld from left to right in order to clearly see the operation. The electrode should be held at a slight angle, as shown in Figure 15.

Before striking an arc, make sure that the work clamp makes good electrical contact with the work. Then lower the head shield and scratch the electrode slowly over the metal. You will see sparks flying. While scratching the metal, lift the electrode about ⅛ in. and the arc will be established. However, do not stop the electrode during the scratching process or it will stick to the work. This scratching should be done relatively slowly; fast jabbing of the electrode will cause it to stick and break the arc.

The arc length is the distance from the tip of the electrode core wire to the base metal. Once the arc has been established, maintaining the correct arc length is extremely important. The arc should be short, approximately 1⁄16 - ⅛ in. long. As the electrode burns off, it must be fed closer to the work to maintain the correct arc length.

The easiest way to determine if the arc has the correct length is by listening to its sound. A nice, short arc has a distinctive cracking sound, similar to eggs frying in a pan of grease. An incorrect, long arc has a hollow blowing or hissing sound.

When welding, constantly watch the puddle of molten metal directly behind the arc. However, do not watch the arc itself. The appearance of the puddle and the ridge where the molten puddle solidifies indicates correct speed (Figure 16). The ridge should be approximately ⅜ in. behind the electrode. If the speed is too fast, the bead will result in a thin, uneven, "wormy" appearance. In general, thin material requires a faster speed, while heavier plates require a slower speed.

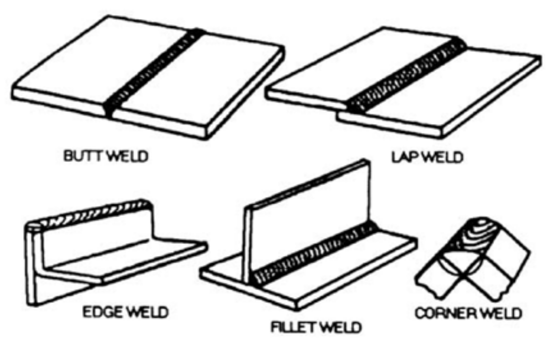


Figure 17: *Various types of welds.*

TYPES OF WELDS

The five most common welded joints are butt welds, fillet welds, lap welds, edge welds, and corner welds. Of these, the butt and fillet welds are the most common (Figure 17).

Butt welds are the most widely used welds. To make a butt weld, place two plates side by side, leaving about 1⁄16 in. space between them for thin materials and ⅛ in. for heavy metals. This distance allows adequate penetration of the weld. Start by tacking the plates at both ends as shown in Figure 18(A); otherwise the heat will cause the plates to move apart as shown in Figure 18(B).

The plates can now be welded together. The weld should run from left to right (if you are right-handed). Point the electrode down in the crack between the two plates, keeping the electrode slightly tilted in the direction of travel (Figure 19). Watch the molten metal to be sure it distributes itself evenly on both edges and between the plates.

Unless a weld penetrates close to 100%, a butt weld will be weaker than the material welded together. In Figure 20, for example, the total weld is only half the thickness of the material, making the weld only about half as strong as the metal.

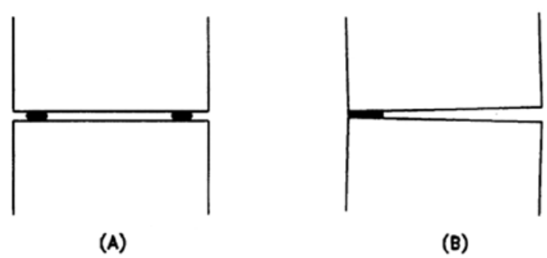


Figure 18: *When performing butt welds, tack the pieces at both ends as shown in (A); starting at one end and working toward the other end will cause the pieces to separate as shown (B).*

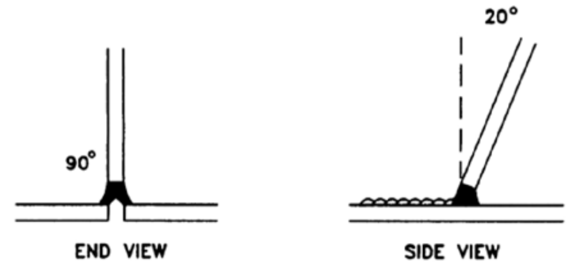


Figure 19: *Correct position of electrode to work for butt welding.*

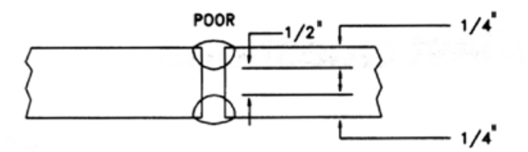


Figure 20: *In this weld, the total weld is only one-half the thickness of the material — making the weld approximately half as strong as the metal.*

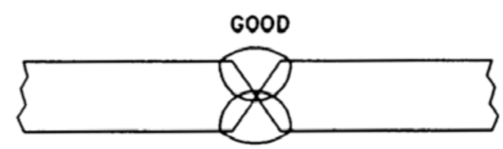


Figure 21: *This is a good welding joint giving 100% penetration.*

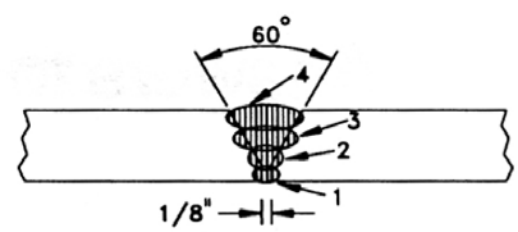


Figure 22: *Successive passes must be used to build up butt welds on heavier material.*

In the example in Figure 21, the joint has been flame-beveled or ground prior to welding so that 100% penetration could be achieved. The weld, if properly made, is as strong or stronger than the original metal. When heavier metals are used, successive passes must be used to build up butt welds, as shown in Figure 22.

Do not start long seams at one end and continue in the same direction because unequal expansion and contraction will result in distortion and severe stresses. The joint should be tack-welded in a few places and completed in sections starting at the center, then moving to a section on one side some distance away, then a similar section on the other side.

FACTORS CAUSING FAULTY WORK

In soldering, the metal runs into the joint at a low temperature that does not spoil the solder, but a welding operation is virtually a local casting of metal done under exceedingly bad conditions for the metal. There is always the risk of weakness developing from strains and slag inclusions. Good results depend on skillful use of the correct filler rods and other tools, and it is not possible for us to give more than general rules.

In the welding of any particular metal, such as the various alloy steels, aluminum, etc., the supplier's instructions are the best guide. Always study the manufacturer's instructions before undertaking any work.

In metallic-arc welding the essential principle is that an electric arc is maintained between a piece of wire — the electrode — and the work being welded. The heat generated by the arc fuses the electrode and the molten metal.

NOTES

Chapter 8 - Making and Replacing Obsolete Gun Parts

Introduction

There are millions of obsolete firearms needing repairs and replacement parts. Some parts are available from manufacturers; others are available from dealers who specialize in obsolete gun parts; others simply are not available at all. In fact, in the near future, much of a gunsmith's work probably will consist of manufacturing parts to restore obsolete firearms, and those gunsmiths who are prepared for this work can, and will, reap dividends.

By using a metal file you can shape almost any gun part by hand from a piece of metal stock, but this takes time and patience. This practice is too time-consuming to be worthwhile. Most gunsmiths use power tools (lathes and milling machines) to turn out replacement parts for obsolete firearms. Even with power tools, turning out a single gun part can be costly. Therefore, whenever available, a replacement part should be purchased.

Most metal components that combine to make a complete firearm, including screws like the ones shown in Figure 1, must be made to accurate dimensions for the gun to function properly. However, regardless of how accurately and nicely finished they are, most gun parts will be of little value if they are not heat-treated properly before their installation. Such treatment can include hardening, tempering, annealing, forging, normalizing, and carburizing. In general, heat-treatment is applied most to carbon and alloy steels.

This is an original firing pin that comes with the spring on the pin for the Winchester 1890 and 1906 pump .22 rifles. If your firing pin is damaged you may have to build one yourself.

Heat-Treatment of Steel

Hardening steel is the process of imparting certain physical properties to the steel so it will resist wear, have tensile strength so it will not stretch or strain, and have sufficient impact strength to withstand blows. The degree of heat and the length of time the heat is applied in each case depend on the material the piece is made of, the shape and size of the piece, and how the piece will be used.

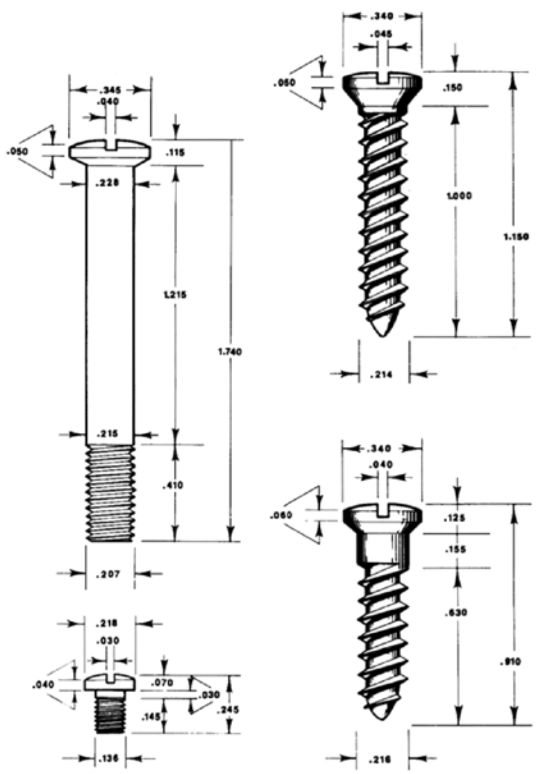


Figure 1*: Gun screws, even those turned to exact dimensions, would quickly become worn if they were not heat-treated before being placed in a firearm.*

Hardening steel consists mainly of heating the part to a predetermined temperature for a predetermined length of time. The temperature at which steel will harden most efficiently is called the *critical temperature*, or *point of recalescence*. In some cases, the part may be heated somewhat beyond this temperature, then quickly immersed in water, which is known as the quench. Many steels used for making firearm parts are quenched in oil or a combination of oil and water, while others are allowed to cool in still air. This latter method is often used when making springs.

TEMPERING

All steel parts that are heated to a high temperature and immediately quenched are subjected to internal strains. When exposed to sudden changes in temperature, the steel is likely to crack unless these strains are relieved by the heat-treating procedure known as *tempering*, sometimes called *drawing*. The procedure involves reheating the steel to a lower temperature than it was subjected to during the hardening process, usually between 300° and 600° F, depending on the degree of hardness desired. Once the tempering temperature has been reached and maintained for the predetermined time, the part should not be quenched; rather, it should be allowed to cool in still air.

ANNEALING

Hardened steel is normally not in a machinable state and must therefore be annealed during the work stage and then rehardened once the machining operation has been completed. *Annealing* is done by applying heat at a temperature of about 15°-100°F below the critical point. The annealing process, when performed correctly, demands a slow, increasing heat until the desired temperature is reached. Then the part is allowed to cool slowly; it is never quenched.

FORGING

In most cases, steel must be heated to *forging* temperatures before it can be shaped. Parts to be forged should be heated slowly to the required temperature, which is usually 200°- 350° F above the critical point. After the steel is removed from the furnace, or forge, it is allowed to cool in still air, away from drafts and dampness.

NORMALIZING

The *normalizing* process is similar to tempering, but the term is usually applied to work that has been forged. Most modern steels do not require this process unless excessive forging strains have been applied. Normalizing requires a temperature 50°- 75° F above the critical point. Gun barrels that have been forged, bored, and rifled often are normalized to relieve stresses so that they will remain straight when tapered, chambered, and threaded to fit on a receiver.

CARBURIZING

Carburizing is a heat-treating process that uses special gases to introduce an extra amount of carbon to low-grade steels so they can be used as substitutes for more expensive steels. This process is also known as case hardening because it is a surface-*hardening* process. The resulting carbon content and depth of hardening, or "case," will depend on the packing mixture, type of equipment, and heating time.

Parts to be case hardened must be machined to dimensions, yet allowances for ground finishes can be made by estimating and controlling the depth of case, which may be 3/16 in. and over. If you do the work properly, the result is a uniformly hard exterior section with no effect on the core or internal structure of the steel. A quench bath is normally used after each part or batch of parts has been heated for the required period of time.

Carburizing is not the only form of surface hardening. *Nitriding* is a similar process that uses ammonia gas as a treating agent. There are also many other methods in current use. A cyanide bath is frequently used when a shallow case is desired, but cyanide is an extremely dangerous chemical to use, and only experienced persons should use it.

Flame-coloring is another method used to obtain a simulated case-hardened effect, especially where there is little surface wear. Induction hardening is another method, which is done by placing the work inside a magnetic field set up by an inductor coil that carries high-frequency currents. The heating and quenching cycle takes only a few seconds for each part.

A cold-treating furnace is often used to stabilize the steel used in precision instruments like calipers, micrometers, etc. The furnace is actually a carbon dioxide refrigerator in which the

***Figure 2**: A Rockwell hardness tester.*

temperature can be reduced to 120° F. This treatment stabilizes the steel and offsets the effects of subsequent temperature changes.

HARDNESS TESTING

Hardness testing involves making an impression on the surface of the steel; the deeper the impression, the softer the metal. One system of hardness testing that has been in use for many years is the *Brinell System*. With this system, a hardened steel ball is pressed into the smooth surface of the metal, making an indentation that can be measured under a microscope. The diameter of this indentation has a definite relationship to the hardness of the metal. Brinell machine manufacturers supply tables showing how these figures relate. From these tables, the hardness number can be obtained.

The *Rockwell method* of testing has been the most popular hardness-testing method for the past several decades. With this method, a dead weight controlled by a series of levers presses a diamond cone into hard metals or a 1⁄16 in. steel ball into softer metals. Fully hardened steels are tested on the C scale with a 120° diamond point, while softer metals, such as annealed or partially hardened steel, are tested on the B scale, using a steel ball. The depth of penetration is measured, and the hardness value is read directly on a dial scale. The harder the material, the higher the Rockwell number. Figure 2 shows a Rockwell Hardness Tester.

The Rockwell method of testing is especially efficient and reliable on fully hardened steels. However, the Brinell method is considered more accurate and reliable for softer materials. The Superficial Rockwell tester is used on very thin sheet or strip steels or to measure hardness at the immediate surface, since it measures only about 0.0003 in. deep, while the standard C scale measures about 0.005 in. deep.

Regardless of what material is being tested, the piece must have a clean, uniform surface in order for you to obtain accurate readings. The usual practice is to either grind both the place to be tested and the portion that rests on the supporting pedestal or rollers, or to clean them by sandblasting, polishing with an emery cloth, or filing.

Instructions for using the Rockwell Hardness Tester are as follows:

- Select the proper penetrating point, clean it thoroughly, place it in the head plunger rod, and tighten it in place.
- Select the proper anvil, clean it thoroughly, and place it on the elevating screw.
- Place the work to be tested securely upon the anvil or table.
- Elevate the specimen into contact with the penetrator and turn the elevating screw until the small pointer is nearly vertical and slightly to the left of the dot. Then turn the screw slightly more until the large pointer is pointing upward.
- Turn the bezel of the dial gauge until the Set arrow on the scale is exactly behind the large pointer.
- Push the crank handle backward. This procedure has applied the load of 100 kilograms.
- Pull the crank handle to the starting position. This lifts the major load, but leaves the minor load on.

Diameter in mm 8,000 kg. load 10 mm. Ball	Hardness No.	Vickers or Firth Hardness No.	C 150 kg. load 120° Diamond Core	B 100 kg. load 1/16" dia. Ball	Scleroscope No.	Apx. Tensile Strength 1,000 PSI
2 .05	898					440
2 .10	857					420
2.15	817					401
2.20	780	1150	70		106	384
2.25	745	1050	68		100	368
2.30	712	960	66		95	352
2.35	682	885	64		91	337
2 .40	653	820	62		87	324
2. 45	627	765	60		84	311
2.50	601	717	58		81	298
2.55	578	675	57		78	287
2.60	555	633	55	120	75	276
2.65	534	598	53	119	72	266
2.70	514	567	52	119	70	256
2.75	495	540	50	117	67	247
2.80	477	515	49	117	65	238
2.85	461	494	47	116	63	229
2.90	444	472	46	115	61	220
2.95	429	454	45	115	59	212
3.00	415	437	44	114	57	204
3.05	401	420	42	113	55	196
3.10	388	404	41	112	54	189
3.15	375	389	40	112	52	182
3.20	363	375	38	110	51	176
3.25	352	363	37	110	49	170
3.30	341	350	36	109	48	165
3.35	331	339	35	109	46	160
3.40	321	327	34	108	45	155
3.45	311	316	33	108	44	150
3.50	302	305	32	107	43	146
3.55	293	296	31	106	42	142
3.60	285	287	30	105	40	138
3.65	277	279	29	104	39	134
3.70	269	270	28	104	38	131
3.75	262	263	26	103	37	128
3.80	255	256	25	102	37	125
3.85	248	248	24	102	36	122
3.90	241	241	23	100	35	119
3.95	235	235	22	99	34	116
4.00	229	229	21	98	33	113
4.05	223	223	20	97	32	110
4.10	217	217	18	96	31	107
4.15	212	212	17	96	31	104
4.20	207	207	16	95	30	101
4.25	202	202	15	94	30	99
4.30	197	197	13	93	29	97
4.35	192	192	12	92	28	95
4.40	187	187	10	91	28	93

Figure 3: *Hardness conversion table.*

- Read the Rockwell C Hardness number, lower the elevating screw, and remove the work from the machine.

The table in Figure 3 shows the relation of the Rockwell and Brinell scales as well as approximate tensile strengths.

Another type of tester is the *Scleroscope Hardness Tester.* With this method of testing, a diamond-tipped hammer falls a fixed distance onto the polished tool surface. You observe the height of the rebound, reading the hardness value from a dial positioned on the instrument.

To operate the scleroscope, lower the instrument onto the work held in the anvil. Turn the knurled knob clockwise for about 5/8 of a turn or until it reaches interval stop. At this point the rebound occurs, and the height of the rebound is indicated on the dial. Releasing the instrument returns it for another cycle of operation. The instrument has the capacity for about 1,000 tests per hour. The hardness values are indicated on a dial scale graduated from 0 to 140.

There is a relation between Rockwell C and Scleroscope hardness. For 62 Rockwell C, the scleroscope reading is 86; for 65 Rockwell C, the scleroscope reading is 92. The table in Figure 3 compares the various testers.

HEAT FOR HEAT-TREATING

When hardening was mainly confined to certain lock parts on muzzleloading rifles and shotguns (for example, the trigger/hammer mechanism), the pieces were simply heated in a blacksmith's forge and plunged into water. Though a skilled worker can still obtain good results this way, this method is no longer compatible with most modern gunsmithing requirements. Now, torches or heat-treating furnaces are used.

There are two distinct types of heat-treating furnaces: the box furnace (Figure 4) and the pot, or crucible, furnace. Both types can be used for all the heat-treating processes previously mentioned. Sources of heat can be natural gas, LP gas, charcoal, electricity, or oil. Of these fuels, electricity, used in electric furnaces, is most commonly used for heating small gun parts.

For heavier classes of work, where lumps of steel have to be heated for forging and rolling operations (for use in firearm receivers, for example), the pieces are handled in a reheating furnace. The ingots, or billets, are laid on a table and pushed into the furnace by a hydraulic or electric pusher, which regulates the speed of the work through the furnace. During their passage, the pieces are carried on water-cooled rails or skid bars.

Figure 4: *A box furnace.*

Figure 5: *Thermocouple pyrometers.*

With the box furnace, the heat-treating is done directly by the heat that is produced within the chamber. With the crucible furnace, the parts to be treated are immersed in a red-hot lead or salt bath. The size of both types of furnaces will vary from huge devices suitable for heat-treating cannon barrels to small bench-top models used for delicate parts for instruments and firearms.

Heat-treating furnaces range in price from a few hundred dollars to several thousand dollars, depending upon size, types of controls, etc. Investing in an electric heat-treating furnace ensures complete control over hardening, tempering, and annealing such items as drift pins, sears, reamers, springs, and many other gun parts and tools requiring proper hardening.

THERMOCOUPLE PYROMETERS

Many gunsmithing shops build simple heat-treating furnaces for specific projects, and most of these homemade furnaces are equipped with some means of measuring the temperature. The most common means is a thermocouple pyrometer with an automatic heat control to maintain the desired temperature for the entire heating period. In general, t*hermocouple pyrometers* consist of two different types of metal or alloy wires, separated from each other except at one end, where they are securely twisted and welded so that both metals will unite. The free ends of the wires are connected to a DC millivoltmeter, while the welded end is inserted where the temperature is to be measured. The heat at this end causes a difference in electric potential; this is indicated on the millivoltmeter, which is calibrated in degrees.

HARDENING AND TEMPERING

To be successful, any form of heat-treatment on critical parts must be done in strict accordance with the recommendations of the steel makers. However, many experienced gunsmiths are skillful in judging the correct temperature at which certain steels should be quenched to obtain the proper hardness. Gunsmiths sometimes use color charts, such as the ones in Figure 5, to show the different colors steel turns when it is heated to various temperatures. Instructions in some gunsmithing books may read, "Quench from a cherry red and draw to a light straw." But these rules-of-thumb are for use only by workers with years of experience — especially when dealing with gun parts that will receive working stresses.

Many gunsmiths are able to quickly harden noncritical parts, such as gun screws or drift pins, by using a torch. Such parts usually can be hardened by the rule-of-thumb methods with satisfactory results.

Carbon and alloy steels normally come in a soft or annealed condition in which they can be machined; if they are forged, they may be further annealed or normalized to correct any adverse effects of the forging operation.

Tool Steels. The common types of straight carbon or low-alloy steels that are intended for water quenching are usually heated to about 1,450° F and then plunged quickly into water. If the

TEMPER COLORS FOR CARBON TOOL STEEL		
Color	Degrees Fahrenheit	Degrees Celsius
Very Faint Yellow	420	215
Light Yellow	440	227
Straw Yellow	460	238
Dark Yellow	480	250
Yellow-Brown	490	255
Spotted Red-Brown	510	265
Brown-Purple	520	270
Full Purple	540	280
Dark Purple	550	288
Full Blue	560	293
Dark Blue	570	300

HEAT COLORS IN MODERATE, DIFFUSED DAYLIGHT		
Color	Degrees Fahrenheit	Degrees Celsius
White	2,250	1,230
Light Yellow	2,100	1,150
Yellow	1,950	1,065
Lemon	1,830	1,000
Orange	1,725	940
Dark Orange	1,630	890
Salmon	1,550	840
Bright Cherry	1,450	790
Cherry	1,375	745
Dark Cherry	1,240	670
Blood Red	1,095	590
Faint Red	985	530

Figure 6: *Tables for average temper and heat colors.*

entire part is to be hardened, it is important that the heating be uniform and thorough.

On some tools it is common practice to heat only the portion of the tool you want to be hard, or sometimes to heat the whole piece, but quench only that portion that must be hard. However, in doing so, you must take care to ensure that the portion that is only partially hardened has no weak section.

The preferred method for creating different degrees of hardness in the same part is to temper to a higher temperature the portion that you want to be softer than the hard part. Temper the quenched part as soon as it is cool enough for you to handle with your bare hands. Tempering temperatures may vary from 225° F to as high as 800° F, but usually a range of 300°- 400° F is used. In some instances you can judge these temperatures by color, but it is usually best to use a heat-treating furnace so you can accurately control the temperature.

The common types of oil-hardening steels are usually quenched in a special type of quenching oil from a temperature of about 1,475° F. These steels should be tempered as soon as they cool. The temperature range for oil-hardening steels is usually 300°- 450° F. Should any warpage occur, it can usually be corrected while the temperature from quenching is still about 500° F. If you attempt this while the piece is cold, it will probably fracture.

Most high-carbon, high-chrome steels can be quenched in either oil or air. If quenched in oil, the quenching temperature should be about 1,750° F; in air the temperature should be about 1,825° F.

These steels can be drawn over a wide range of temperatures up to about 900° F without a great reduction in hardness. They maintain accuracy in size very well during hardening, especially when air cooled.

Other types of air-hardening steels can be hardened in air from 1,550° to 1,800° F. As stated before, the tempering range for these steels is about 300°-400° F.

High-speed steels are usually hardened in oil or air from about 2,350° F and are almost invariably preheated to about 1,600° F. The time at high heat is limited to just long enough to heat

the steel properly, since overheating will cause the steel to expand and can even burn the edges. Tempering is usually done at about 1,050° F. However, a wide variety of quenching temperatures and drawing temperatures are often combined to obtain special values in toughness and hardness. Heating in a special atmosphere, heating in neutral salt baths, quenching in hot lead at about 1,000° F, and other special methods are often used with high-speed steel to obtain good surface results.

When working with tool steels, do not allow undue strains to occur during heating or quenching, or the steel can crack and fracture. Experience and good judgment are very important when working with tool steels. It is always a good idea to preheat tool steel so that it cannot be forced through the range of transformation, or critical range, at a high speed of heat absorption. It is also a good idea to protect the surfaces of intricate parts by packing them in a neutral material such as cast iron chips or used carburizing compound before the heating operation.

Milling and Grinding

The milling machine is a versatile, power-driven machine tool that performs a variety of machining operations quickly and accurately. It is particularly useful when a large number of interchangeable pieces must be cut to exact dimensions, and it is adaptable to both large and small parts of intricate design. In fact, manufacturing of the modern firearm would not have been practical without the milling machine.

The two main elements of the milling machine are a movable table and a revolving cutter. The table carries the work to a rotating cutter, which remains in a fixed position while the work moves to form the shape or design. You can usually adjust the speed of the cutter from 50 rpm to 500 rpm or more.

To use the milling machine, first secure the workpiece to the milling table with clamps. You can then adjust the table — up or down in a vertical plane, back and forth horizontally, or in a cross-feed manner — to manipulate the work under the cutter. These movements can be made under power by means of rapid-transverse controls, or by duplicate hand controls. In mass-production operations, the table is often manipulated by computer controls that automatically adjust the table to form the desired shape of the workpiece. When precision work is required on only a few pieces, the adjustments are usually made with calibrated hand controls on which each graduation represents 0.001 in. of table movement.

Depending upon the type of milling machine — horizontal or vertical (Figures 7 and 8) — the operator first selects and adjusts the revolving

Figure 7*: Horizontal milling, boring and drilling machine.*

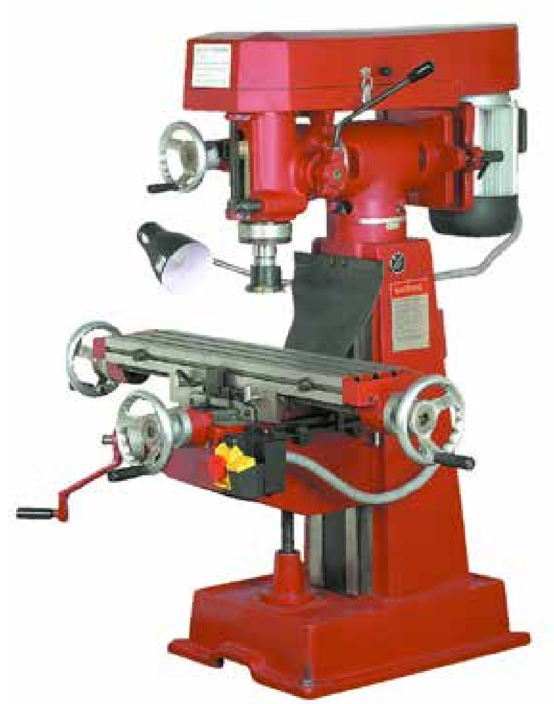


Figure 8*: Vertical milling machine set up to mill helical gear teeth.*

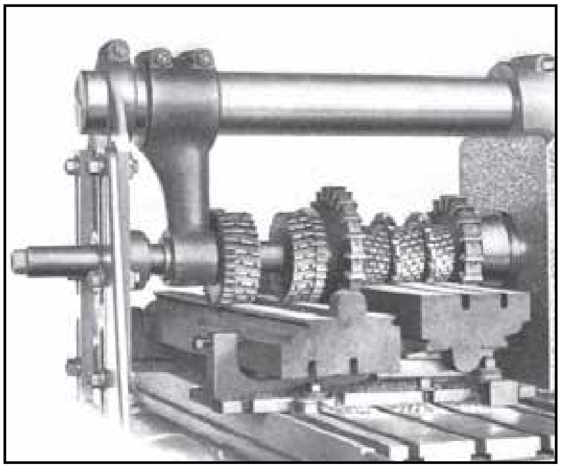


Figure 9: *Gang mill setup with multiple cutters.*

cutter. For a horizontal milling machine, an arbor shaft is fitted into the power-driven spindle. Spacing collars are used to locate the cutter at any position on the arbor, while additional collars and a key hold the cutter in place when the arbor nut is tightened and locked to provide a positive drive. A large collar is then set on the end of the arbor to act as a bearing for the overarm bracket, which is slid out and locked in place to support the shaft.

The selection and mounting of the cutter depend on the construction of the machine and the type of work to be performed. The relation of the headstock to the table must first be determined; that is, whether it should be on the right side or the left side of the table. Furthermore, the direction of cutting movement and the rotation of the cutter teeth must be determined. In general, the cutter should be as small as the job permits, since a shorter cut will allow for greater feed speeds and will require less power.

On most machines, you can set the cutter in motion by engaging a quick-acting clutch. The work is then carried up to the cutter and is secured against vibration by various levers. You can set a selective feed indicator, graduated in inches per minutes, to govern the speed at which the work is fed.

Successful milling depends upon the flexibility of movement of the table, the accuracy with which the work is adjusted in relation to the cutter, and the use of the correct tools at the proper speeds. Avoid excessive speeds; they dull the cutter and produce a coarse surface. Figure 9 shows a gang mill setup with multiple cutters for speed cutting.

SPEED AND FEED

The two most vital factors for effective work are the speed of the milling cutter and the longitudinal feed of the work table. A range of cutting speeds is ordinarily provided by a gearcase on the milling machine, while feed is automatic in three directions.

It is not practical to give strict rules for cutting speeds and feeds on various materials because these rules depend on shop conditions, the type of work being done, the age and condition of the milling machine, the quality of steel used for the cutters, whether the cutters are solid or inserted-tooth cutters, the skill and experience of the operator, etc. With so many variables, it is impossible to give precise figures that will apply in every case. The best we can offer is a rough guide for you to follow until you have established the best speeds and feeds for a particular job. The table in Figure 10 should get you started.

METAL	TYPE OF CUTTER	
	HIGH-SPEED STEEL	TUNGSTEN- OR TITANIUM-CARBIDE
	ft. per min.	*ft. per min.*
Aluminum	1,300–1,600	2,600–4,900
Brass	160–200	350–380
Bronze	130–165	250–330
Cast Iron	50–65	200–230
Duralumin	980–1,300	1,960–2,450
Electron	980–1,300	1,960–2,450
Malleable Cast Iron	60–65	200–230
Mild Steel	50–65	130–200
Nickel Chrome Steel	25–45	100–130

Figure 10*: Rule-of-thumb feeds for various types of metal and cutters.*

DEPTH OF CUT

Many beginning milling machine operators seem to believe that the quickest way to finish work is to make heavy cuts. Actually, it is much more effective to use a light cut with a fast feed. Unless the margin of material to be removed is very small, it is better to take numerous cuts with a fast feed than to take one heavy cut with a slow feed. The reason for this is that a heavy cut generates greater heat at the cutting edge, and this heat will draw the temper of the cutting edges of the tool. Even if the tool is made of the finest high-speed steel and will go on cutting steadily when at a red heat, excessive vibration or chatter can occur, damaging the cutting edges. Furthermore, if the cutter is an inserted-tooth cutter, in which the cutting blades or edges are an extremely hard cutting alloy, such as tungsten-carbide, the vibration will probably cause fracture. Even if you make only a slightly heavier cut than is desirable, the cutter will probably need much more frequent sharpening, wasting your time and increasing your tool costs.

Another common error is to run the cutter too fast. This shortens the life of the cutting edges and uses more power, while producing an inferior finish. You can usually sharpen the teeth of milling cutters without causing them to lose their form, and frequent sharpening of the teeth is one of the essentials of successful milling.

MEASURING CUTTING SPEED

When a workpiece is fed to the rotating cutter, the rate at which the metal shaving or chip is removed is the *cutting speed*. Cutting speed is expressed in feet per minute of the tooth edge of the milling cutter as it removes a shaving. To arrive at the correct rpm of a cutter, divide the cutting speed by the circumference in feet of the cutter. For example, if the cutter measures 2 ft. around the circumference, and a speed of 40 ft. per minute is desired, it will take 20 revolutions of the cutter per minute to give this rate of speed.

Feed is the distance the work advances against each successive tooth of the cutter. It is governed by the depth and width of the cut, the type of

cut, the size of the cutter, the number of teeth on the cutter, the proportion of the thickness to diameter, the rpm of the cutter, the manner in which the cutter is mounted, the condition and power of the milling machine, and the rigidity with which the work to be milled is held.

With such a long list of variables, it is difficult to give specific recommendations regarding feed. However, in general, a roughing cut is intended solely to remove surplus metal before the final, or finishing, cut is taken, and it should have a coarse feed. Leave about 1/64 in. for the finishing cut.

The rate of feed has a noticeable effect on the surface finish. Slower feeds usually produce a smoother surface.

In setting up a job on the milling machine, the operator should have everything on hand before starting the machine. While no great skill is required to operate a milling machine, extreme accuracy in setup is essential, and this depends on correct calculations.

HOLDING THE WORK

There are numerous ways to hold the work when using a milling machine. It can be secured directly to the worktable, gripped in a special fixture, fixed to an angle plate or other tool, held in a vise, held between centers, or held in a chuck. Test the accuracy of the holding arrangement before you begin. A clamp will damage a polished or finished surface unless the jaws are padded. Oil the threads of nuts and bolts on the mill frequently, and use the correct wrenches for tightening or loosening the nuts to prevent rounding their corners. If you use a wrench on a nut with rounded corners, it could slip, possibly injuring you.

After you have secured the job, make sure nothing has been left lying around that will damage the machine or be swept off the table and cause injury. Thin pieces should be clamped down carefully to avoid distortion caused by excessive pressure. Rigidity of the work is essential. You should support the work with jacks or shims wherever necessary. Try to prevent the work from springing under the cutter.

Set the table as near to the machine column as possible. As you set up the job, loosen the clamping screws, but be sure you tighten them before you begin milling.

ADJUSTING THE CUTTER

The job is usually set up before the cutter adjustment is made, except when end mills or face mills are being used. After the work has been clamped down correctly, make sure the cutter is completely clean. Clean out the tapered hole in the machine spindle or collar and make sure it is dry. Clean the arbor shank of any grease and dirt, which can cause the arbor to slip in the spindle. Thoroughly clean faces before placing the cutter on the arbor. Beginners occasionally run the cutter in the wrong direction. This will smash the teeth. Check for proper direction of cutter rotation by first making sure that the driving spindle revolves in the correct manner in relation to the work, and that the cutter is properly mounted on its arbor and revolves likewise (Figure 11).

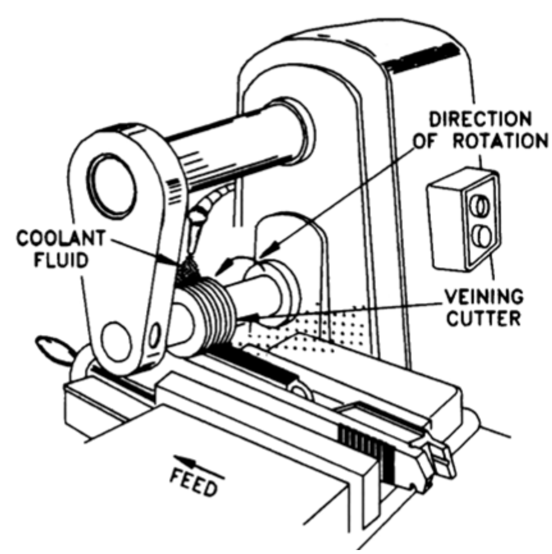


***Figure 11**: Proper direction of cutter rotation is important in milling.*

Set the cutter as near to the spindle as the job allows. This lessens strain on the bearings and brings the job closer to the body of the machine. If you have to change the cutter, either for re-sharpening or because it is worn out, you do not need to take out the arbor, as long as the replacement cutter is of the same diameter. Never hit the cutter with a hammer or other instrument, either to drive it onto the arbor or to remove it. This could damage the teeth and crack the tool.

EXAMINING THE MACHINE

If the part to be milled is small, you should loosen it a little on the worktable after you have completed the roughing cuts. This will relieve the stress caused by the clamping down, and will prevent distortion. If the work is gripped in the milling machine vise, test the zero mark (at which the swiveling angle graduations begin) for accurate positioning by putting a long straightedge in the vise and, by means of a square on the worktable, swiveling the vise until the straightedge is parallel with the slots of the table.

If the part to be milled is delicate and has thin sections, it is best to use a slow feed, even though the job will take longer. Success in milling depends on the condition of the milling machine. Do not neglect regular examination of the machine spindle, arbor, and feed screw, which, if allowed to become worn, will cause wobble or play and affect the work. Do not allow the table guides to become loose, and keep the driving mechanism in good running order.

If the job demands a heavy cut, take great care to prevent chatter. Bad mounting of the cutter on its arbor can cause considerable wear. The arbor is forced out of line under the pressure and blunts the cutter teeth. If you see that the arbor might deflect, remount the cutter close to the spindle nose, or, if it is already in position, support the arbor.

CHOOSING THE CUTTER

The choice of the right type of cutter is important for efficient milling. The cutter must have the proper form of tooth and be made of a suitable material. Several hundred different kinds of cutters are manufactured. The following paragraphs give a brief description of the more common cutters.

Helical, or *spiral*, *mills* have flat ends and their teeth are formed in a steep spiral around the body. The steeper the spiral, the smoother the cutting action (Figure 12(A)). These mills are particularly useful for milling thin metal, copper bars, and other springy materials because they do not spring away from the work. Helical mills are also good for heavy cuts.

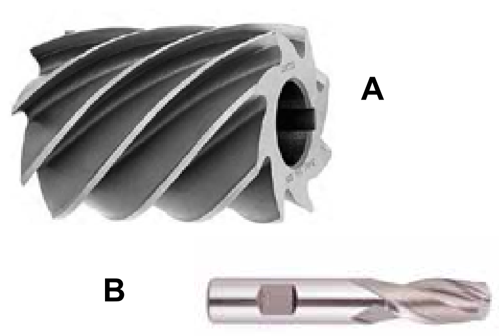


Figure 12: *(A) A helical or spiral mill, with teeth arranged in a deep spiral around the body. (B) A two-lipped, slotting end mill.*

Figure 13: *Two types of double-angle cutters.*

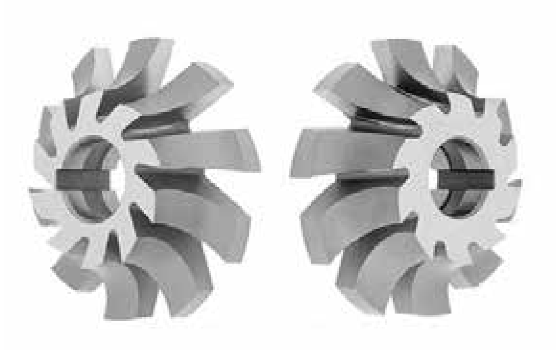


Figure 14: *Three corner-rounding cutters for finishing edges and corners of gun receivers.*

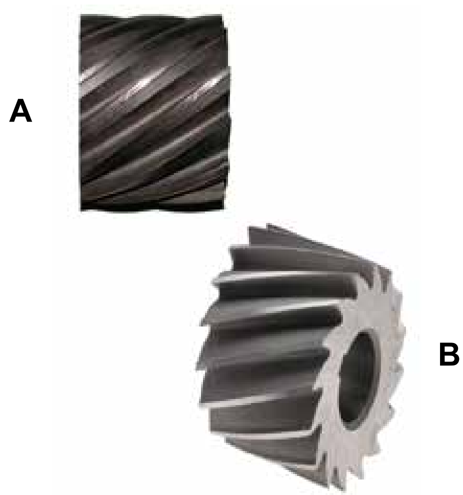


Figure 15: *Two types of plain cutters. The cutter shown in (A) is for ordinary work, while the coarser-tooth type (B) is for heavy work.*

Figure 16: *Facing cutters.*

Two-lipped, slotting end mills, shown in Figure 12(B), are designed to cut slots and keyways. They have teeth not only on their sides, parallel to the axis, but also on one end. This arrangement enables them to mill deep slots in solid metal. These tools should be run at high surface speeds with either a deep cut and a fine feed, or a rather shallow cut and a medium feed. Ample lubrication is desirable.

Double-angle cutters, shown in Figure 13, are basically the same as plain mill cutters. The only difference is that double-angle cutters are curved on the cutting surface rather than flat. These cutters will make a rounded cut rather than a flat cut.

Corner-rounding cutters, shown in Figure 14, are designed for finishing the edges and corners of a part, and can be manufactured for any required radius. They are available in either right- or left-hand cuts, and either single or double cutters.

Plain cutters, shown in Figure 15, have ends that are ground flat. These tools are used to mill plain surfaces, and they can be used for either right- or left-hand cuts by simply reversing the cutter on the arbor or shaft. Manufacturers usually supply this type of cutter for ordinary work unless you order something different. Whenever possible, use the type with a coarse tooth and a steep spiral.

Facing cutters have teeth on the outer edge and one end (Figure 16). These cutters are not reversible on their arbors, so when you order them, you must indicate whether you want right- or left-hand cutters.

The cutter shown on the left is a right-hand cutter. The coarse-type cutter shown on the right should be used whenever possible, since it cuts more freely and takes less power.

The *slotting cutter*, shown in Figure 17, has teeth on the outer edge only, with the sides ground slightly concave to give clearance when cutting. It is used primarily for accurately milling slots, and is generally made with straight-cut teeth up to ¾ in. wide and with spiral teeth above this

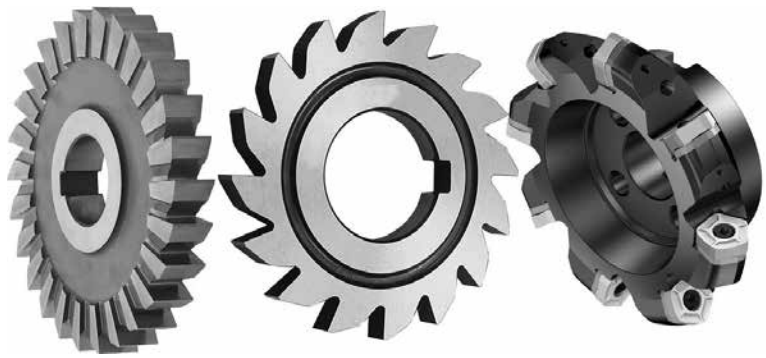


Figure 17*: From left to right: a slotting cutter, a side cutter, and a face cutter.*

Figure 18*: The metal-sitting saw has slightly concave sides.*

Figure 19*: Shell-end mills have teeth on the outer edge and one end.*

thickness. Standard cutters are made with a thickness tolerance of plus or minus 0.001 in. The corners of the teeth on this type of cutter show signs of wear first, so as soon as you notice wear, you should resharpen the teeth.

Side and *face cutters*, also shown in Figure 17, have teeth on the face and both sides. They are sometimes called straddle mills. For heavy work, the coarse-tooth side cutter is recommended. These cutters are supplied with a width tolerance of +0.005 in. and -0.001 in. They can, of course, be used for milling slots, but they are not designed for this type of work, and their suitability for it depends on how accurate the slots need to be.

The cutter for sawing metal, or *metal slitting saw* as it is commonly called, has teeth on the edge only, with the sides ground concave for clearance when cutting (Figure 18). It is used for a variety of jobs, from putting deep slots in heavy sections of steel to cutting through thin tubes. However, a single saw is not capable of covering this range of work satisfactorily, for while a fairly large pitch, or spacing of teeth, is required for solid work, it is of very little use for thin sections of work.

When ordering new saws, specify the class of work they will be used for or the required pitch or number of teeth. These saws are regularly made with diameters ranging from 2½ to 8 in.

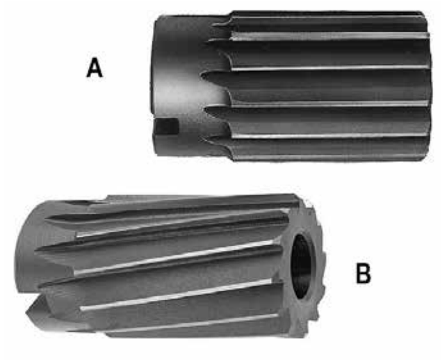


Figure 20*: Shell reamers are used to enlarge deep or wide holes more cheaply than by an ordinary reamer. Flutes may be either (A) straight (B) spiral.*

Figure 21*: Concave (left) and convex (right) milling cutters are used to make many types of gun parts. The front faces only are resharpened when they are ground.*

and come in thicknesses ranging from 1/32 in. to ¼ in. For sawing off large pieces of metal, it is not economical to use the thinnest saw listed (1/32 in.), since it is a delicate tool that requires careful handling. Slitting cutters are also made with side chip clearance.

Shell end mills, shown in Figure 19, have teeth on the outer edge and one end, and are designed for mounting on an arbor. Beginners often confuse them with facing cutters; the difference is that shell end mills have cutting edges greater in length than half the diameter of the cutter, whereas facing cutters have cutting edges less than half the diameter of the cutter. Since shell end mills are not reversible on their arbors, they are made to cut either left-hand or right-hand cuts. In principle, these tools are exactly the same as ordinary solid end mills, but they are marketed in the shell form for the larger sizes in order to reduce expense. Manufactured with a diameter tolerance of +0.010 in. and -0.001 in., they are made for ordinary work and also for especially heavy work.

Ordinary reamers are designed to enlarge the diameters of holes already made by another tool, such as a twist drill or punch. A part is often cast with holes made by cores inserted in the mold. The *shell reamer* serves exactly the same purpose as the ordinary reamer, but was introduced to save expense in enlarging deep holes or holes of large diameter, where the cost of ordinary reamers would be excessive. This type of tool is manufactured with a diameter tolerance of +0.0006 in. and +0.0012 in. for the smaller sizes and +0.0007 in. and +0.0014 in. for the larger sizes. They are made with either straight or spiral flutes (Figure 20). The most commonly used reamer is that with spiral flutes, as shown in Figure 20(A).

The reamer shown in Figure 20(B), a *rose shell reamer*, has straight flutes. This type of reamer enlarges from a smaller diameter and is easy to resharpen. However, it is not quite as adaptable to the same class of finish. Made with either parallel or taper holes, these tools must not be confused with shell end mills; they are not accurate enough to meet the same requirements as the shell end mill. You can avoid this confusion by remembering that standard shell reamers have flutes greater in length than the diameter, and have no teeth on the end.

Concave and *convex milling cutters*, shown in Figure 21, are used on the milling machine in order to produce either concave slots or convex edges. They are almost always made of the same machine-relieved type, so resharpening is simple, with only the front faces being ground. This design also enables the cutters to reproduce the same profile, within very narrow limits, until worn out.

Figure 22*: Rough and finish gear cutters: a single-angle cutter is shown on the far right.*

Figure 22 shows a gear cutter used in the milling machine to produce gear teeth. There are usually eight cutters to a set, enabling gears with 12 to any number of teeth to be cut. These cutters should always be kept well-sharpened, because on the sides of some of them only a small cutting clearance can be allowed. Unless they are kept in good condition, rubbing or grinding in the cut will occur. This is detrimental to cutter life. They must be sharpened only on the front faces, and this operation must be done carefully. Otherwise, the cutter will not produce the same outline after sharpening as it did before.

Wherever possible, the sharp comers of the teeth should be beveled off. This increases the life of the cutters and at the same time enables a heavier feed to be employed. The angles of these cutters are measured as shown in Figure 23, and are either right-hand or left-hand. The cutters can be made to any desired angle.

Equal angle cutters, shown in Figure 24, are similar in design to double-angle cutters, but in this instance both angles at the intersection are the same. The nominal angle of the cutter is the angle between the two sides. This cutter can be made to all angles.

Relief is the bevel-off of the teeth of a cutter. Relief is used to prevent the teeth from rubbing. Generally, there are two types of relief — straight and curved.

Straight tooth cutters have less rubbing than curved tooth cutters, as shown in Figure 25. They cut more freely because each tooth is cutting with line or point contact only. The teeth not only last longer, but also will stand from two to five times more regrinding. Clean, sharp-edged teeth with strictly constant profile or form and ample support behind the cutting edges eliminate rubbing on the back and sides.

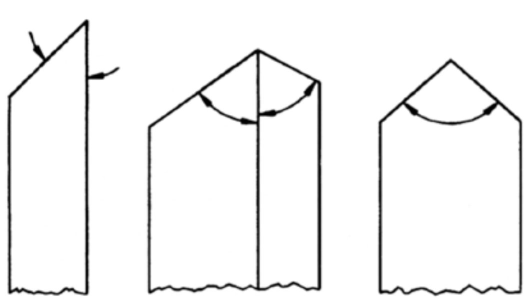


Figure 23*: Method of measuring angles on a single-angle cutter.*

Figure 24*: Equal-angle cutters.*

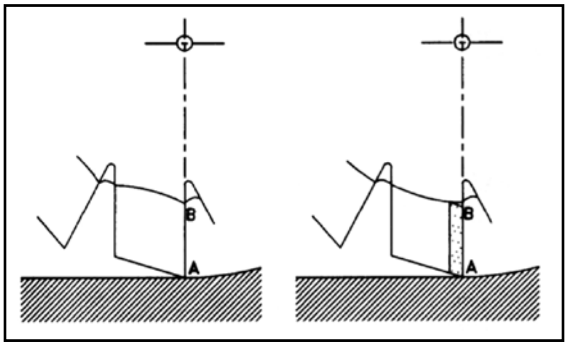


Figure 25: *The straight-tooth cutter at left shows how the effect of rubbing is eliminated, while the one at the right will receive a certain amount of rubbing.*

Except in a few cutters where the teeth are comparatively short, cutters have what is termed double relief. As shown in Figure 26, the front of the tooth is given approximately 17° clearance, and at a point approximately midway in the useful cutting zone of the tooth there is a change in direction of the relief; this again gives approximately 17° clearance to the teeth.

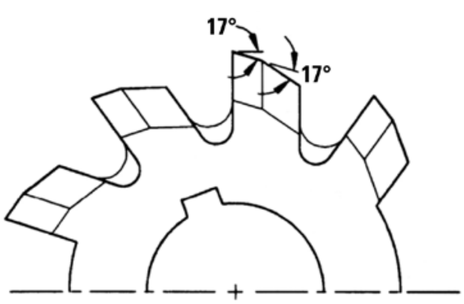


Figure 26: *Cutters used over the past 30 years always have double relief as indicated above. The clearance angle is usually 17°.*

CHOICE OF MACHINE

You should give a lot of thought to your choice of a milling machine. Keep in mind how many parts are to be milled, the type of work to be milled, the amount of power necessary, and the means of power transmission—by individual, group, or lineshaft drive. These factors govern the decision of whether the machine should be cone-driven or constant-speed driven. The choice of a plain, universal, or vertical type of machine depends on whether or not it will be the sole milling machine in the shop, by the amount of time it will be used for spiral cutting, and by whether it will be employed for jobbing or for manufacturing. Other concerns are the need to mill plane surfaces, and to do die sinking or gang milling. Finally, the decision between automatic or non-automatic hinges on the number of pieces you expect to produce.

INDEXING

Indexing means rotating the work on its axis to an exact indicated amount. There are many indexing operations involved in milling, fluting, and gear cutting. If you want to cut a gear, each tooth must be an exact and identical distance from its neighbor. The same is true of the flutes of a reamer or a milling cutter. You must calculate the required setting of the machine to give the proper spacing. Index tables are usually provided to help you with these calculations.

Indexing can be plain or universal. In plain indexing the index plate has three circles of holes — 24, 30, and 26 — and will index any number that divides evenly into anyone of these. Universal indexing gives divisions of all types up to 400, which meets the needs of most shops. If larger numbers have to be indexed, the manufacturer of the milling machine provides a high-number indexing attachment.

Making Springs

Whenever possible, you should use ready-made springs. Ready-made springs are inexpensive when compared to the time you would spend making one from scratch. However, manufactured replacement springs are not available for every firearm, which means that you may have to hand-fashion a spring if such a firearm is to be put back into service.

It is not difficult to make a useful replacement spring for a firearm, provided you understand certain basic techniques.

The type of spring that you will most often have to make is the mainspring used in some of the older shotguns (Figure 27). There is so much variation in these springs that it is extremely difficult to find factory-made replacements that will always fit exactly. Even the replacement springs that are manufactured for a specific gun will almost always have to be modified and fitted to the individual gun.

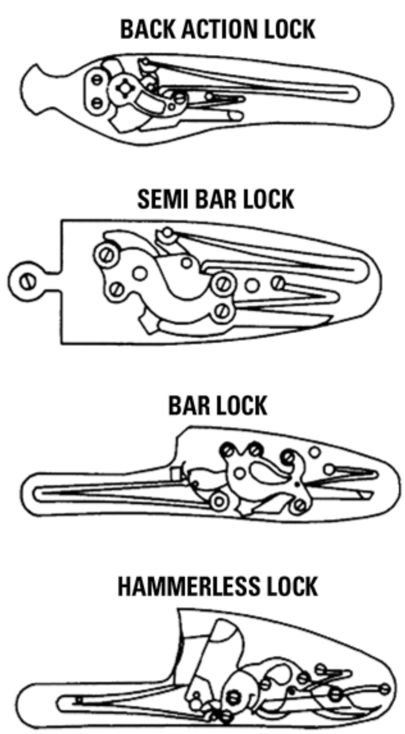


***Figure 27**: Some typical mainsprings used in older shotguns.*

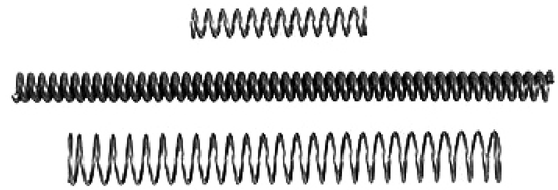


***Figure 28**: A few of the many types of coil springs sold by Brownells.*

Next in line are the springs for box lock shotguns, which are also difficult to obtain. Then come the frizzen springs, sear springs, and trigger springs. The techniques in this section will show you how to make all of them.

SPRING STOCK

Various assortments of spring stock are available from gunsmithing supply houses, such as Brownells. Coil springs, like the ones shown in Figure 28, or compression gun springs, like the ones in Figure 29, are normally available already tempered, so you only have to cut them to the required length. For example, Brownells No. 69 coil springs are packed several sizes to the carton and are cut in 12 in. lengths. This assortment is designed primarily for the softer-acting gun springs.

Next is the Brownells No. 150 kit, which contains small spring wire in diameters from 0.020 in. to 0.120 in. The spring stock in this assortment is ready to make into springs, or any piece that can be annealed and retempered.

Flat spring stock is available in the Brownells No. 149 kit, which contains 12 assorted pieces in widths from $\frac{3}{16}$ in. to $\frac{3}{8}$ in., and in thicknesses from $\frac{1}{16}$ in. to $\frac{1}{8}$ in. This assortment is annealed, and you purchase it in a soft state, but you can forge and temper it into gun-quality springs.

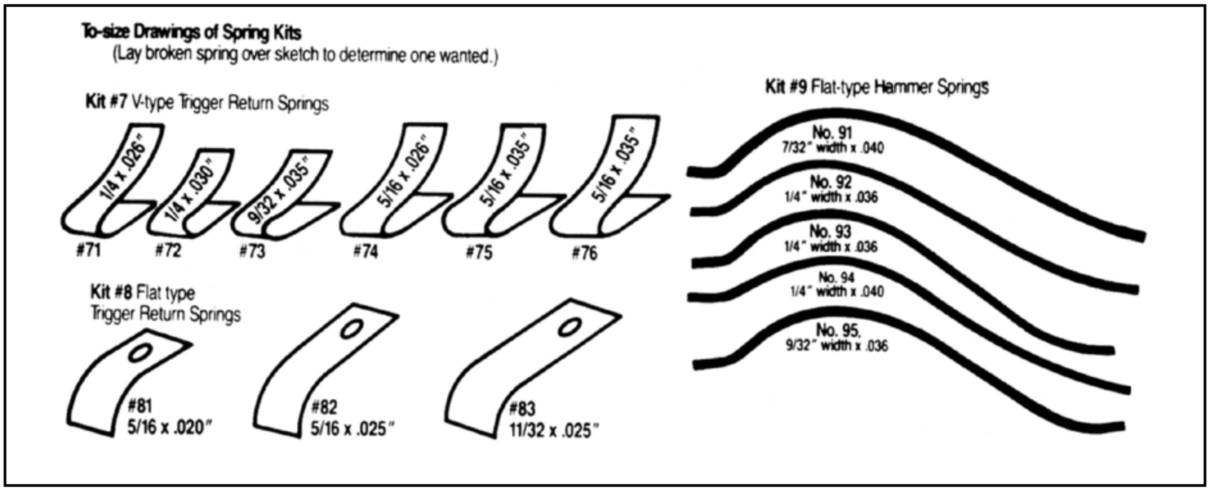


Figure 29: *Replacement springs for almost all of the older revolvers are available from Brownells.*

Brownells also carries extra-wide, flat spring stock and music wire spring stock in a variety of sizes. These combinations should suffice for 99% of the gunsmith's needs.

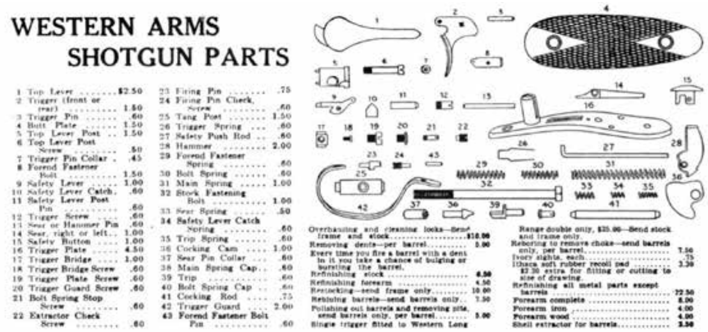
Do not overlook the possibility of good spring stock lying around your shop or home. Old clock springs, for example, can be used as raw material for gun springs once they have been cleaned up and annealed. You can then forge and temper them for practically any use. However, be cautious of modern springs. Modern metallurgy has developed certain steels for specific applications, many of which are not suitable for gun springs. Regardless of the type of raw material obtained, it will have to be annealed or softened so that it can be readily worked with a file, hacksaw, and other tools necessary to obtain the required shape prior to tempering.

INITIAL PREPARATION

It is always best to have the broken spring close at hand when preparing to make a new one. If this is not possible, be prepared for a lot of time-consuming research and work that must be done on a trial-and-error basis.

Here are a few suggestions:

- Try to locate a drawing of the spring in either a sectional or perspective view. Drawings can usually be found in old parts catalogs. Back issues of the *Shooter's Bible* are good sources for these drawings, like the one shown in Figure 30.
- Determine the approximate physical dimensions of the spring you need. For example, if a sidelock on a double shotgun on which you are working is 4 in. in actual length, and the length of the same sidelock in the drawing is 1 in., then the drawing has been reduced in scale to one-fourth of the original. Keeping this in mind, you can obtain the approximate dimensions of a spring in the drawing; that is, obtain all actual dimensions in the drawing and then multiply each by four (in this case). Of course, you will still have to do some trial-and-error fitting, but at least you will have a starting point.
- On many sidelock shotguns requiring the replacement of a broken mainspring, one of the mainsprings will still be intact



WESTERN ARMS
SHOTGUN PARTS

1 Top Lever	$2.50	23 Firing Pin	.75
2 Trigger (front or rear)	1.50	24 Firing Pin Check Screw	.60
3 Trigger Pin	.60	25 Tang Post	1.50
4 Butt Plate	1.50	26 Trigger Spring	.60
5 Top Lever Post	1.50	27 Safety Push Rod	.60
6 Top Lever Post Screw	.50	28 Hammer	2.00
7 Trigger Pin Collar	.45	29 Forend Fastener Spring	.60
8 Forend Fastener Bolt	1.50	30 Bolt Spring	.60
9 Safety Lever	1.00	31 Main Spring	1.00
10 Safety Lever Catch	.60	32 Stock Fastening Bolt	1.00
11 Safety Lever Post Pin	.60	33 Sear Spring	.50
12 Trigger Screw	.60	34 Safety Lever Catch Spring	.60
13 Sear or Hammer Pin	.60	35 Trip Spring	.60
14 Sear, right or left	1.00	36 Cocking Cam	1.00
15 Safety Button	1.00	37 Sear Pin Collar	.60
16 Trigger Plate	4.50	38 Main Spring Cap	.60
17 Trigger Bridge	1.00	39 Trip	.60
18 Trigger Bridge Screw	.60	40 Bolt Spring Cap	.60
19 Trigger Plate Screw	.60	41 Cocking Rod	.75
20 Trigger Guard Screw	.60	42 Trigger Guard	2.00
21 Bolt Spring Stop Screw	.60	43 Forend Fastener Bolt Pin	.60
22 Extractor Check Screw	.60		

Overhauling and cleaning locks—Send frame and stock	$10.00
Removing dents—per barrel	3.00
Every time you fire a barrel with a dent in it you take a chance of bulging or bursting the barrel.	
Refinishing stock	6.50
Refinishing forearm	4.50
Restocking—send frame only	10.00
Rebluing barrels—send barrels only	7.50
Polishing out barrels and removing pits, send barrels only, per barrel	5.00
Single trigger fitted to Western Long Range double only, $25.00—Send stock and frame only.	
Reboring to remove choke—send barrels only, per barrel	7.50
Ivory sights, each	.75
Ithaca soft rubber recoil pad; $2.50 extra for fitting or cutting to size of drawing.	3.30
Refinishing all metal parts except barrels	22.50
Forearm complete	8.00
Forearm iron	4.00
Forearm wood	4.00
Shell extractor for barrels	3.50

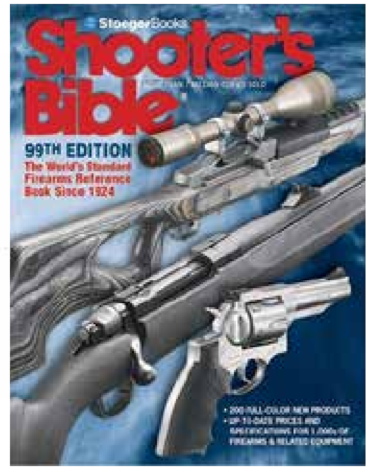


***Figure 30**: This parts list —from an old Stoger Shooter's Bible — can tell the gunsmith a lot about the shape of missing springs when the original cannot be located.*

within the mechanism. This is also true for boxlock actions. The remaining good spring can be used as a template to make a duplicate of the broken spring. In this case, curvatures and retaining nipples will have to be reversed (like a mirror image); however, anyone capable of making a spring should experience little difficulty in laying out these changes.

- Try to find another firearm like the one you are working on. Disassemble the good weapon, then take measurements of the good spring to use in making a new one for the broken gun.
- Assuming that all the pieces of the broken spring are in your possession, reconstruct them (using epoxy glue to hold them in place) to obtain the overall shape to act as a guide for making the new spring. Study the broken spring carefully, observing the shape of the taper. In the case of a flat leaf spring, the arms are tapered to withstand considerable movement. This taper should be even, so that the strain on the whole arm will be constant. If a section changes too abruptly from thick to thin, then all the strain will fall on the thin part, especially at the point where the difference occurs. Heavy mainsprings must always taper evenly from the fold to the hook; otherwise you can expect an early breakage. Frizzen and sear springs are not quite as critical; the arms on these springs do not receive the great amount of deflection that the arms on mainsprings do.

An experienced springmaker can apply a quick heat, give two or three blows with a hammer, and form a hook or an eye that will make up part of a flat spring. It looks easy, but it is extremely difficult to accomplish without many years of experience. The beginner will need considerable time to accomplish the same thing, and should not be discouraged by initial failures.

MAKING THE V SPRING

Two types of stock may be used to make a V spring: flat stock and drill rod of high carbon content. Either can be hardened and tempered. If the latter is used, select a rod of sufficient diameter to allow the round edges to be squared

off with either a grinder or a file. Once selected, measure the distance from the end of the broken spring arm (the one you are copying) to the bottom of the V. Then, with a hacksaw, slit the rod to a little more than the depth required. For example, if your measurement was 1¾ in., make the slit about 1⅞ in. so you will have a little to spare.

Again, take measurements of the existing broken springs and then square up the rod with the slit on a grinding wheel to within about 3⁄32 in. of the finished width and thickness at the bottom of the V. Be careful not to overheat the metal. This calls for very slow grinding; if you see any colors start to form, stop immediately and let the steel cool.

Use a pair of calipers to check the width and thickness constantly at the bottom of the V; or you might want to use a combination of grinding and filing, as the situation dictates.

At this point the arms of the new spring, formed by the slit in the middle of the rod, are bent, as shown in Figure 31, and cut to the exact length. Some gunsmiths like to do this bending while the spring is hot, but usually it can be done when the spring is cold, if you are careful. Frequently match the existing broken spring to ensure that the arms, or leaves, are bent to the exact shape as the original. To ensure even pressure throughout the entire lengths of these leaves, the arms must be tapered evenly. For this operation, the use of flat files and a small grinding wheel in a moto-tool is ideal. Take care not to heat or burn the metal. Try to obtain the exact taper (or close to it) of the original spring. When the leaves have been shaped and tapered, all dimensions should be double-checked.

Next comes polishing. This may be done with abrasive paper wrapped around files, with a power buffing wheel, or with a combination of the two. There are many reasons for polishing the spring at this point. First, if tool marks are not polished down, the spring will probably break from a stress concentration around such a mark in the spring's surface. Also, the metal must be polished to allow the colors to show through during the heat-treatment.

It is best to use a temperature-controlled furnace for heat-treating springs. However, few professionals — and practically no beginners — have such an apparatus, so you may have to improvise. Set up some fire bricks on your bench. A small stovepipe wire is used to hold the spring

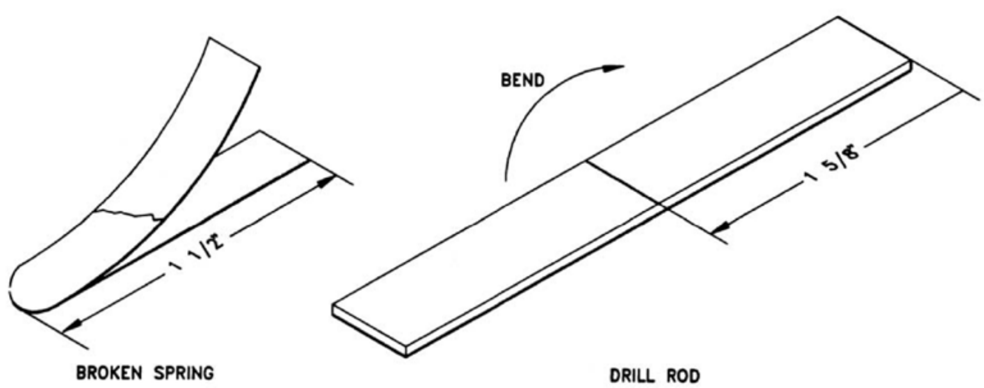


Figure 31: *Making a V spring.*

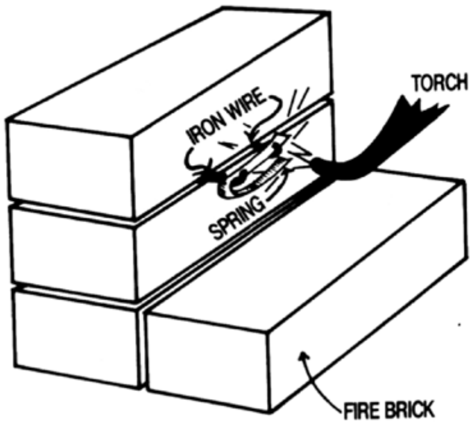


***Figure 32**: Arrangement of fire bricks for tempering gun springs.*

against the bricks during the heat-treating process. Anything larger than these pieces of wire will draw heat away from the workpiece and cause the spring to temper unevenly, resulting in a poor spring that will probably break after only a few compressions. You will also want another piece of thin wire to lift the spring when it reaches the right temperature in the correct length of time. Attach this wire to the spring before you begin heating the stock.

You will need to quench the spring in the recommended solution, which will vary depending upon the type of drill rod used. Usually, drill rods from ¼ in. to ¾ in. are designed for quenching in oil, while smaller ones are best quenched in water. Some gunsmiths like to use water with a light quenching oil floating on top. It may take some experimenting to determine which solution is best for the spring stock you are using.

With the solution in a suitable container close by, and the spring in position on the wires against the fire bricks, as shown in Figure 32, heat the metal as evenly as possible with a propane or similar torch. When the spring reaches a cherry to bright cherry color (1,400°-1,500° F), hold this color for about 20 seconds. Then, immediately quench the spring in the chosen solution, holding the spring by the long wire attached to the spring before heating it.

At this point, the spring is very hot, so handle it carefully. Be careful if you are using an oil-quenching bath. Some have low flash points, and will ignite when hot metal is dropped in them. It is often easier to work outdoors in the shade than to work inside a building.

After the heated spring cools in the quenching solution, it will be hard, but brittle. It can be easily broken at this stage, so handle it with care, the way you would handle a glass rod. It must now be tempered to produce the toughness required for a good gun spring. But first, the metal must be polished again so that you can detect the colors the metal takes on during heating. You can use the power buffer you used to polish the spring prior to heating; however, since the spring is now very brittle, it is a good idea to do the polishing by hand, using abrasive paper, being very careful not to break the spring.

Tempering temperatures will vary with the type of spring stock used, the length of time the hardening temperature was held, and the temperature used in the hardening. Most texts recommend a temperature between 600° and 650° F, which should give a color between dark blue and gray.

A dark straw to yellow brown, which is produced at between 465° and 500° F, works best on some steels. You might have to do some experimenting, especially if you do not have a temperature-controlled furnace. There is one good thing about such experimenting: If you do not get it right the first time, you can reheat the part to cherry red and try it again. As long as

you do not break the brittle part, and you polish it each time you heat it, you can probably try different temperatures many times without having to shape a new spring.

Now that the piece has been polished brightly and is in position on the wires against the fire bricks, use the torch to heat the spring evenly and slowly until it reaches the desired color. Keep the flame moving all over the piece (at this color) for about 15 seconds, then slowly remove the flame and let the piece cool. Protect it against any breeze that might cool it too quickly. Some gunsmiths like to completely cover the spring with lime and let it cool slowly this way.

When the spring is completely cooled to room temperature, again remove all scale and polish the spring. Check the measurements, especially the distance between the two leaves.

Completely compress the spring between the jaws of a bench vise, then release the pressure. Once more, check the distance between the two leaves of the spring. If the leaves return to their original distance and the spring does not break, you have a perfect spring. If not, give it another try. If you get this right on the first try, you did better than most people.

Another approach to this tempering is to use molten lead. Many shooters cast their own bullets and have an electric melting pot on hand, or at least a ladle in which lead can be melted. Pure lead melts at 620° F, so if you heat the lead just until it melts, you should be just about right. At this point, remove the lead from the heat and use a wire to submerge the spring into the molten lead. Be careful not to let the spring touch the sides of the melting pot; the temperature might be hotter there. Hold the spring under the lead for about 15 seconds; then, remove it and let it cool slowly at room temperature.

Depending upon the metal used to make the spring, a better temper might be obtained by dipping the spring in water after removing it from the lead. Some experimentation may be necessary. We offer these different techniques for you to try so you can find the one that works best for your individual needs. Every springmaker has techniques that work best for him or her. All of these techniques will make a spring, but one technique might suit your situation better.

V-type mainsprings can be made from flat spring stock, such as that offered by Brownells. Examine the broken spring carefully, measuring its thickness, width, and length. Then select a spring stock that comes closest to these measurements to minimize the labor required to shape the spring.

The sharp bend required for the V-notch in the spring is difficult to bend cold without cracking or breaking, so it is best to grip the stock in a bench vise and heat the area to be bent to a cherry red; then partially bend the V with pliers. Complete the bend by holding a torch to it and forging it with a hammer. Thus formed, it must be slowly air cooled to remain soft enough for the remaining forming and polishing.

The curved profile required for the spring can then be easily formed by cold bending. At this point, the spring should roughly resemble the finished spring, with the exception of being slightly oversize in thickness, width, and length. Now comes the final shaping to obtain exact dimensions and, most importantly, the proper taper. This portion of the project can be done entirely by hand, using files, a bench grinder,

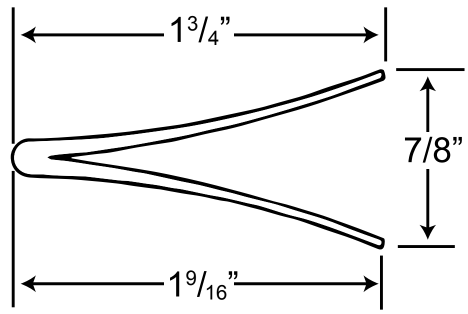


***Figure 33**: A typical V-notch gun spring that can be made.*

and abrasive paper. Some professional shops use the milling machine for this operation, which is fine if one is available. Once exactly shaped, the entire spring must be polished and free from defects.

Heat-treating is now necessary to give the spring elasticity and resilience. Should the spring crack while testing, try again, using a slightly higher temperature. If the spring remains bent rather than springing back after compression, the spring stock may have too low a carbon content, in which case you will have to look for a different metal. It can also indicate faulty heat-treatment, such as quenching from too low a temperature, quenching too slowly, or tempering at too high a temperature. Fortunately, a soft spring is not ruined; it can be heat-treated again and again until the correct results are obtained.

Figure 33 shows a typical V-notch gun spring that can be made with this procedure.

MAKING COMPLEX SPRINGS

Up to this point, we have only discussed simple V-type mainsprings. These are sufficient for many makes of box lock actions, but mainsprings for sidelocks will be more elaborate. They contain hooks, crooks, pegs, slots, and eyes, all of which are complicated. However, after gaining some experience, you should be able to shape practically any design. The process is going to be time-consuming, but with patience and knowledge you can perfect the technique.

Upon examining designs of sidelock mainsprings, you may find one where the anchor eye is at right angles to the leaves. This type of spring can be made by first making two cuts on each side of the flat stock, heating the area to cherry red, and then turning the end piece 90°. If you take careful measurements and your planning is correct, you will have the leaf just the right width after allowing for the removal of the unwanted part of the back strip, which is removed to form a peg on the side of the spring.

Some of the embellishments found on mainsprings are not really necessary. Many mainsprings will function normally without them. So try to understand the reasoning behind certain shapes, and then simplify your design as much as possible. For example, on certain frizzen springs, the eye is normally as deep as the leaf, but in many cases, this depth is not necessary. Try one with a shallow eye. Chances are it will work just as well, and it is much easier to make. If you have oxyacetylene welding equipment, twist the eyepiece, drill the required hole, and then use a welding rod to build up around the eye, giving it the depth desired. Allow it to cool slowly so it will anneal properly. Then redrill the hole and

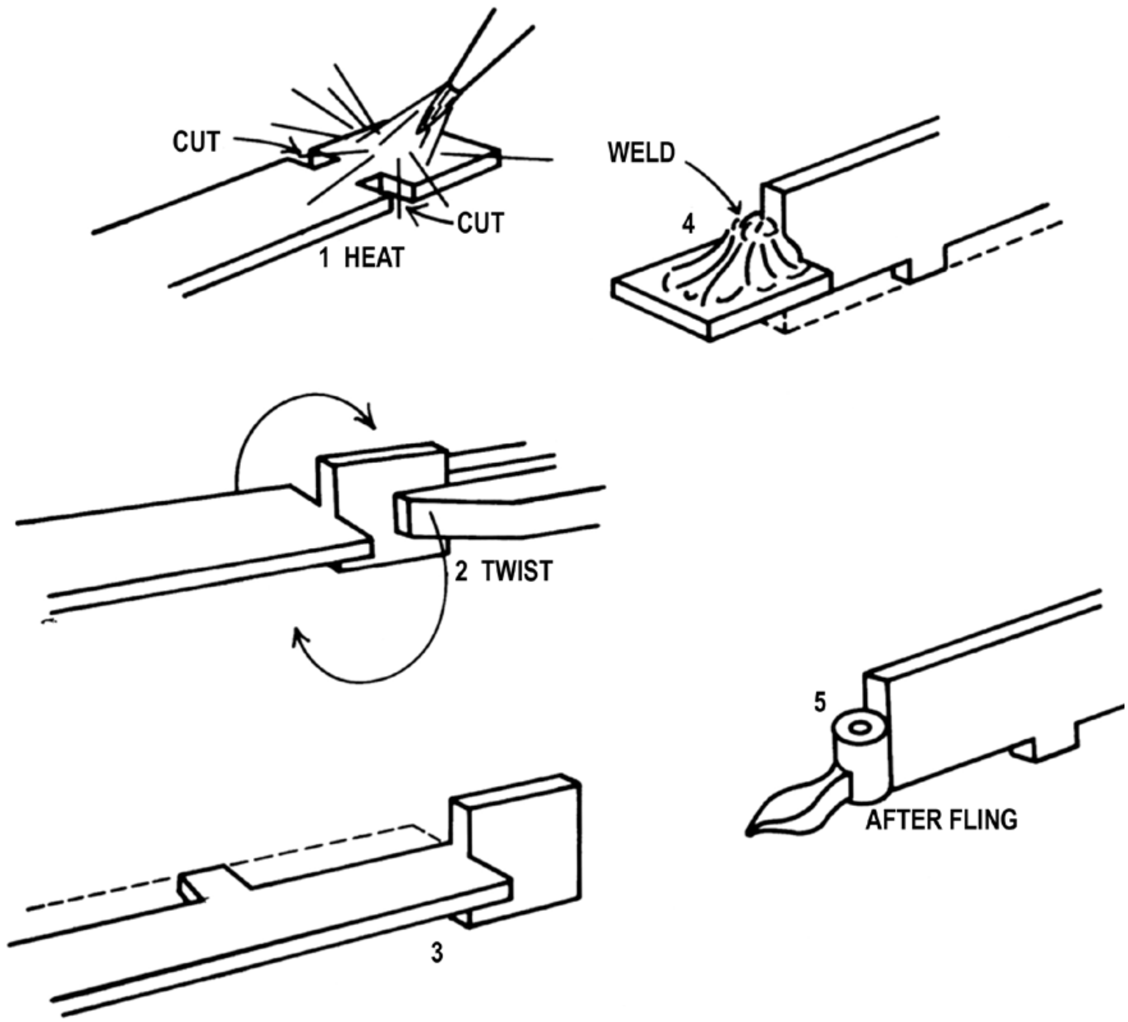


Figure 34: *Here, a piece of flat stock is first notched and heated; then the end of the stock is twisted, as shown. The stock is revolved to match the spring needed, and the weld is built up, then filed to the exact shape. Note that a small hole has been drilled in this spring to match the original.*

shape the area with files. These procedures are shown in Figure 34.

Many professionals balk at the idea of welding springs, but it can be done, provided the spring is retempered. Even springs that have been in a fire can sometimes be brought back to life by further hardening and retempering. Similarly, a broken peg can be effectively repaired by silver soldering. Merely anneal the spring, drill into the leaf with a slightly smaller drill bit than the old peg (about one-third the depth of the leaf width), turn or file a new peg, and silver solder it in place. You will need a solder with a melting point above 1,500° F for this operation. Then the entire spring can be rehardened and tempered.

FORMING HOOKS

Many mainsprings contain hooks at the end of one leaf. Forming these hooks can be a bit complicated. Once you have formed the basic spring, leave some extra metal on the end of the leaf where the hook will be located. Narrow this widened area further so that it is the same width

as the tumbler. To make the hook, heat the leaf at the end of the taper and turn the thick stub upward. Then heat the upright piece, keeping the actual bend as cool as possible. Next, pull the tip of the metal back down again. This method is similar to forming an eye in the end of an electrical wire for connection to a terminal. Mastering this technique requires some practice. Remember, since you have left some extra thickness in this portion of the leaf, the arc or bend does not have to be too great; you can obtain further roundness when you shape the hook later on with a file. This procedure is shown in Figure 35.

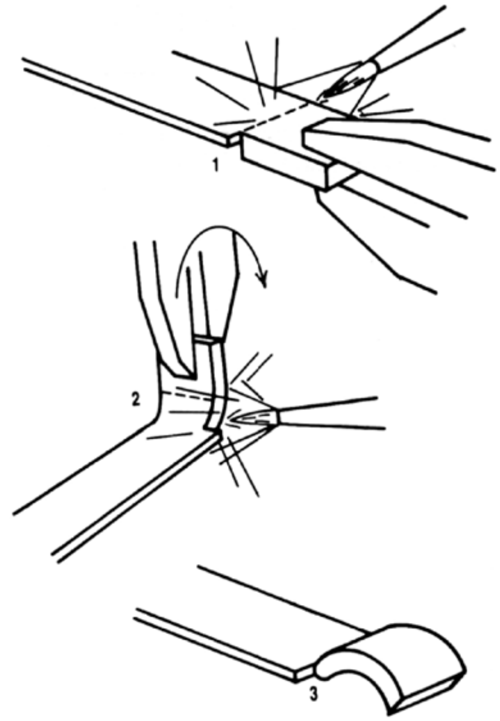


Figure 35*: To make a hook on the end of flat stock, first heat the piece and bend upward with pliers; then apply heat to the center and bend downward. File to the exact size and shape.*

Cut off any surplus steel from the point of the hook and try the resulting shape with the existing spring. The hook can be adjusted by heating the toe of the hook and then using pliers to close it in or out.

Some hooks also contain a notch. Before the spring is hardened, drill a row of holes at the required location using a small drill bit with light pressure. Then use a set of Swiss files to smooth the interior of the slot.

Mainsprings with lugs on the ends of the leaves are best formed from a solid piece cut complete with the lug intact. Further shaping can be done by forging, using a vise, anvil, or swaging blocks. This takes much practice.

Bear in mind that springmaking, like nearly all gunsmithing techniques, takes considerable practice. Seldom will you obtain perfect results on your first attempt, but once you have learned the technique, you will not forget it.

MAKING GUN PARTS

Gun parts other than springs are usually made on machine shop tools such as the lathe, milling machine, etc., but if you have patience, you can make almost any small part using a set of metal files. You just need to know the shape and dimensions of the part, and how to take and transfer correct measurements.

When making a new part from scratch, it is always best to have the old part available. If the old part is broken, use glue or epoxy to temporarily hold the pieces together for measuring. If you do not have the part, refer to old parts catalogs for the general shape and appearance.

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